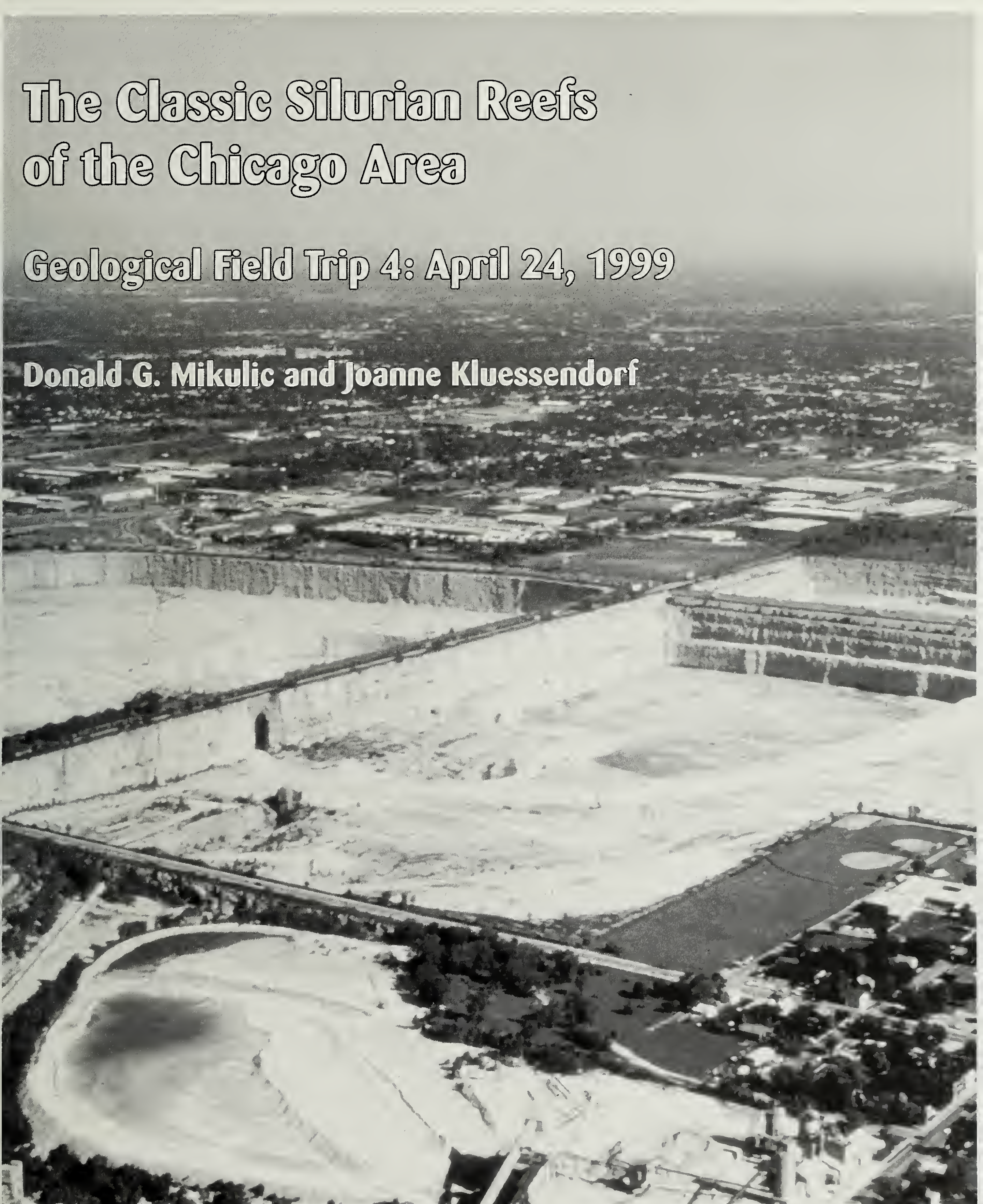
The Classic Silurian Reefs of the Chicago Area

Geological Field Trip 4: April 24, 1999

Donald G. Mikulic and Joanne Kluessendorf



ILLINOIS STATE GEOLOGICAL SURVEY
Champaign, Illinois
ISGS Guidebook 29

33rd Annual Meeting, April 1999
North-Central Section
Geological Society of America

Meeting Organizers
Dennis R. Kolata, Chair
Ardith K. Hansel, Vice Chair

Field Trip Coordinators
Janis D. Treworgy
Myrna M. Killey

Scientific Editors
Janis D. Treworgy
Myrna M. Killey
Jonathan H. Goodwin

Publications Coordinator
Ellen M. Wolf

Graphics
Cynthia A. Briedis
Pamella K. Carrillo
Jacquelyn L. Hannah
Michael W. Knapp

Photography
Joel M. Dexter

Editors
Thomas N. McGeary
R. Stuart Tarr

William W. Shilts, Chief
Illinois State Geological Survey
615 East Peabody Drive
Champaign, IL 61820-6964
(217) 333-4747
http://www.isgs.uiuc.edu

This guidebook was previously published by Western Michigan University for the 27th Annual Meeting, North-Central Section, Geological Society of America, April 1994, Kalamazoo, Michigan. Reprinted with permission.

⊛ printed with soybean ink on recycled paper

Printed by authority of the State of Illinois/1999/600

The Classic Silurian Reefs of the Chicago Area

Donald G. Mikulic
Illinois State Geological Survey
Joanne Kluessendorf
Department of Geology, University of Illinois

ISGS Guidebook 29

Geological Field Trip 4: April 24, 1999
North-Central Section, Geological Society of America
33rd Annual Meeting, Champaign–Urbana, Illinois
April 22–23, 1999

sponsored by
Illinois State Geological Survey
615 East Peabody Drive
Champaign, IL 61820-6964

University of Illinois, Department of Geology
1301 West Green Street
Urbana, IL 61801-2999

U.S. Geological Survey, Water Resources Division
221 North Broadway Avenue
Urbana, IL 61801

Cover photo *Aerial view of the Material Service Corp. at Thornton Illinois*

Dedication

This guidebook is dedicated to the memory of Heinz A. Lowenstam and Robert R. Shrock, both of whom made outstanding contributions to the study of ancient reefs, and especially the Silurian reefs of the Great Lakes region. Their work, which integrated sedimentology, paleoecology and paleontology, was comprehensive and innovative, and has stood the test of time. Although their reef studies were conducted many years ago, Heinz and Bob were still keenly interested in hearing what new insight the latest exposures revealed or what new controversy they sparked. Both men were true friends who encouraged and inspired us, and we miss them greatly.

CONTENTS

FIGURES

INTRODUCTION

Silurian reefs of the Chicago area have maintained both economic and scientific importance for more than 150 years. The high-purity dolomite from these reefs was a major source of lime throughout the nineteenth century. Today it is quarried extensively for crushed stone and forms the foundation of a $100 million-a-year stone and lime industry in the Chicago area. Scientifically, Chicago reefs are important models not only for Silurian reefs, but for Paleozoic reefs in general. This field trip guide, which is a revision of the guidebook by Mikulic and Kluessendorf (1985), features the three localities (Bridgeport, Stony Island, Thornton) that figured most prominently in the history of these reef studies.

General Geology

The Silurian geology of the Chicago region is summarized in Willman (1973), Mikulic, *et al.* (1985), and Mikulic (1990). In general, all Paleozoic rocks in northeastern Illinois dip eastward toward the Michigan Basin, and the thickest section of Silurian rocks lies along the Lake Michigan shore in Cook County. The lowermost Silurian unit, the Wilhelmi Formation, varies considerably in thickness as it fills depressions and thins over high areas on the eroded Upper Ordovician Maquoketa surface (Fig. 1). The Wilhelmi is highly argillaceous, comprising, in part, reworked Maquoketa shale. As the Maquoketa surface was gradually covered and the supply of clastics diminished, purer carbonate sediments were deposited during deposition of the overlying Elwood and Kankakee Dolomites. These units also thin and thicken in the same manner as the Wilhelmi, although to a lesser extent.

The disconformable boundary between the Kankakee and the overlying Joliet Dolomite is the most prominent stratigraphic marker within the Silurian rocks of northeastern Illinois and signifies a type 2 sequence boundary, the most pronounced within the Silurian of the Midwest (Kluessendorf and Mikulic, 1992, in press). The Joliet Dolomite is divided into three members: Brandon Bridge, Markgraf and Romeo. Throughout most of northeastern Illinois the Sugar Run Dolomite succeeds the Joliet, but it is indistinguishable at many reef localities.

The Racine Dolomite, the uppermost Silurian unit in the Chicago area, constitutes more than half the thickness of the Silurian section in eastern Cook County (Fig. 1). It is considered late Wenlockian-Ludlovian in age (Berry and Boucot, 1970), and comprises both reef and interreef facies. The reef facies consists of high-purity dolomite, whereas the lithology of the interreef facies varies widely from

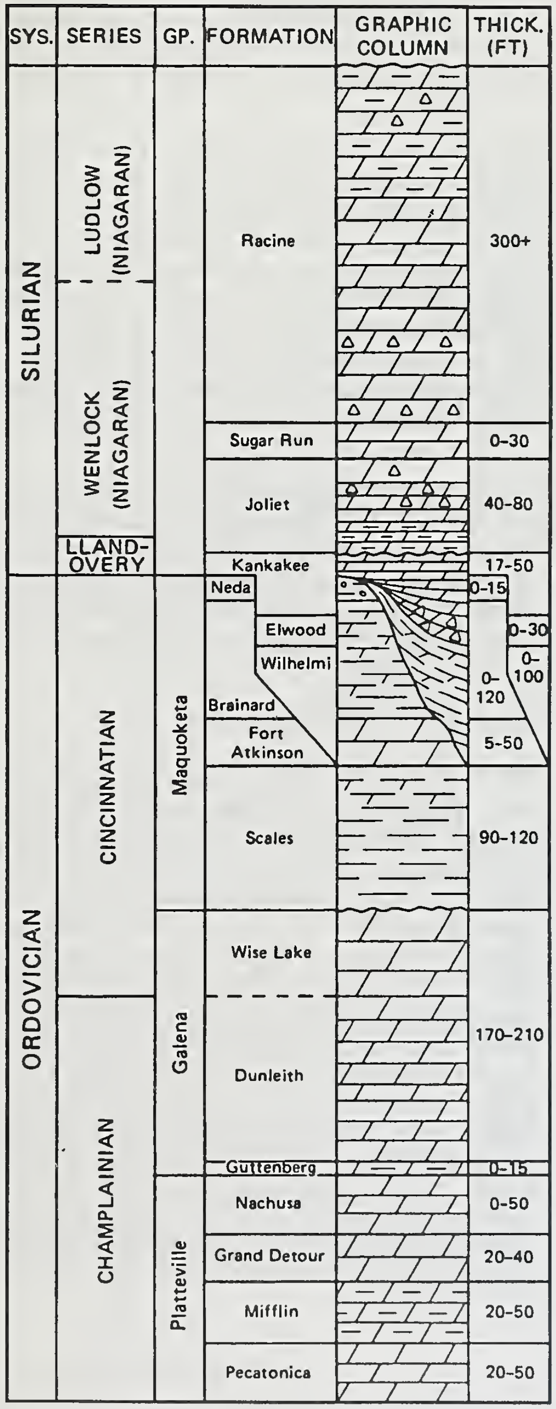


Figure 1 Silurian and Ordovician post-Ancell Group strata of northeastern Illinois. (after Mikulic, *et al.,* 1985)

very pure to highly argillaceous dolomite, with or without chert. Although the interreef facies dominates the Racine volumetrically in the Chicago area, it is poorly exposed because the reef facies is quarried preferentially. However, interreef strata are exposed at Thornton, McCook, Lemont, and along the Calumet-Sag Channel near Blue Island where the famous *Lecthaylus* soft-bodied biota occurs (Lowenstam, 1948).

Racine reefs throughout most of Cook County occur as individual structures or in small groups surrounded by interreef strata. Reefs range in size from less than 10 feet (3 m) to more than 1.5 miles (2.4 km) in diameter, and from three feet (1 m) to at least 300 feet (92 m) in thickness. Original thickness of the larger reefs is equivocal because they have been planed off by post-Silurian erosion and Quaternary glaciation. Some reefs, especially many of the largest such as Thornton and Stony Island, started to develop during deposition of the basal Racine or older strata; other reefs (e.g., McCook, Lyons) originated during later Racine deposition. Because the reefs are erosion resistant, they occur as hills at the bedrock surface and some formed islands or shoals in Quaternary lakes.

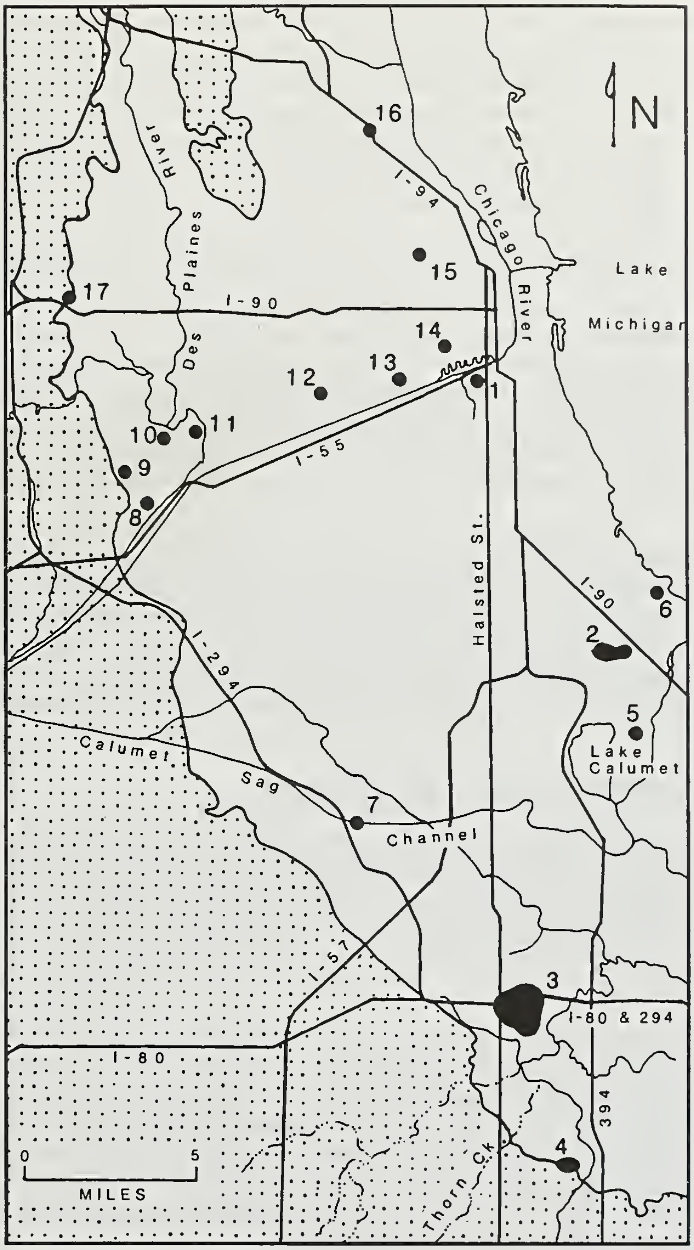
During the Silurian, these reefs were located on a shallow carbonate platform between the proto-Michigan and the proto-Illinois basins. A carbonate bank that existed at the edge of the proto-Michigan Basin extends into east-central Cook County, indicated by a thick section of massive- to thick-bedded pure Racine Dolomite exposed at Bridgeport, the Addison Street roadcut, and formerly at the Chicago Union Lime Works and Artesian quarries (Fig. 2). Dipping flank strata and the diverse biota characteristic of other Chicago reefs are present only in the upper 20-30 feet (6-9 m) of the Racine at Bridgeport, and were reported only from that interval at the Chicago Union Lime Works quarry (Bannister, 1868; Bretz, 1939). With the exception of these upper strata, the Racine at these localities is characterized by pelmatozoan debris, with robust stem sections of the crinoid *Crotalocrinus* are especially conspicuous at the Addison Street roadcut.

Previously, Devonian rocks in the Chicago area were known only from the Des Plaines Disturbance and fissure fills (Kluessendorf, *et al.*, 1988). Recently, however, they have been found in the subsurface of southeastern Cook County, where as much as 30 ft (9 m) of Middle Devonian hypersaline carbonates succeed the Racine Dolomite unconformably (Mikulic, 1990). These strata lie at a lower elevation than nearby Silurian reef-controlled bedrock hills, indicating that the reefs remained topographic highs following pre-Middle Devonian erosion.

Chicago Stone Industry

Silurian rocks, and Racine reefs in particular, have been an important source of essential construction materials in the Chicago area for more than 150 years (Mikulic, 1989). The production of lime and other stone products derived from these reefs was one of the first industries in Chicago, with some quarries opening as early as the 1830s. The early history of these quarries is poorly documented, but most were probably small operations run on an intermittent basis. Demand for stone increased as the city grew and, after 1850, Stearns Lime and Stone Company, the Chicago Union Lime Works, and other firms operated larger quarries on a more regular basis. Following the opening of the Illinois and Michigan Canal in 1848 and subsequent establishment of the Lemont-Joliet building stone industry, the already limited production of building stone in Chicago diminished further still (Mikulic, 1989). Asphalt-stained reef rock from the Artesian quarries, which was used in a few landmark buildings, such as the Chicago Coliseum (Libby Prison Museum) and the Second Presbyterian Church, was the only Chicago building stone quarried after this date. Lime was the chief product of most Chicago quarries throughout the latter half of the nineteenth century, but macadamized street-paving, which was increasing in popularity, generated an increased demand for crushed stone. This great demand for paving materials gave rise to some of the largest quarrying companies, including the Dolese and Shepard Company (now part of Vulcan Materials) which began business as a paving contractor in 1868 and would expand to operate as many as eight quarries during the later 1800s.

Figure 2 Map of the Chicago Lake Plain in central and southern Cook County, Illinois, showing location of quarries, Silurian reefs and other locations mentioned in the text. Stippling marks morainal deposits bordering the lake plain on the west and north.



1. Bridgeport reef and quarry (see text)
2. Stony Island reef and quarries (see text)
3. Thornton reef and quarries (see text)
4. Chicago Heights reef and quarries; two small nineteenth century stone pits were located near the intersection of Cottage Grove Avenue and U. S. Highway 30 at East Chicago Heights (now Ford Heights).
5. Torrence Avenue reef in subsurface (see Stony Island description for details)
6. Cheltenham reef and quarries; an outcrop was present at the site of the South District Filtration Plant (formerly Rocky Ledge Park) (Bretz, 1939) and small late nineteenth century quarries operated by Dolese and Shepard Company were located northwest of the intersection of East 75th Street and South Exchange Avenue and north of the intersection of East 82nd Street and South Houston Avenue.
7. Calumet Sag Channel spoilbanks west of Blue Island, containing *Lecthaylus* biota in Racine Dolomite interreef strata
8. McCook quarry, operated by Vulcan Materials (see Mikulic, *et al.*, 1985, for details)
9. Federal quarry at McCook, operated by Material Service Corporation (see Mikulic, *et al.*, 1985, for details)
10. Riverside (Lyons) quarry, operated by Material Service Corporation (see Mikulic, *et al.*, 1985, for details)
11. Cermak Park reef and small nineteenth century quarry (see Mikulic, *et al.*, 1985, for details)
12. Hawthorne (Cicero) reef and quarry, just east of the intersection of West 32nd Street and Cicero Avenue (State Highway 50) in Cicero. Large nineteenth century quarry operated by Dolese and Shepard Company, closed in 1915, and filled with garbage.
13. City of Chicago House of Corrections (Bridewell) quarry, east of West 27th Street and South Sacramento Avenue; quarry operated by convict labor from the 1904 until the early 1940s, when it was abandoned and filled.
14. Chicago Union Lime Works reef and quarries; quarries at present site of Harrison Park, southeast of South Damen and West 18th Street were operated from the mid-1800s until 1929, when they were abandoned and filled with garbage.
15. Artesian reef and quarries; two large and several small quarries in the vicinity of the intersection of West Grand Avenue and North Western Avenue and south through Smith Field Park were operated from the early 1800s by Artesian Lime and Stone Company, and J. Rice and Son, among others, until the last was filled with garbage in the 1930s.
16. Addison Street-Interstate 94 roadcut
17. Hillside quarry; large quarry operated from 1800s to the late 1970s; now a landfill site

In the early 1900s, urban expansion and a drop in the demand for lime brought about the demise of most Chicago quarries. By then, many sites were surrounded by residential or industrial neighbors and, having reached their property boundaries, operators were forced to quarry deeper non-reef reserves. For example, the Chicago Union Lime Works quarry, was mined through the entire Silurian section to a depth of 380 feet (117 m) before being abandoned in 1929. The value of these mined-out quarries did not decline immediately, however, as most were converted into much-needed garbage dumps for the ever-growing city.

While local supply was dwindling, the need for crushed stone, particularly for Racine reef rock, in turn-of-the-century Chicago, was rising dramatically with the increased use of two important new construction materials, concrete and asphalt. Because crushed stone could then be transported economically into the city by rail, rural quarries surrounded by undeveloped land, such as Thornton and McCook, became prime stone-producing sites. Several Chicago quarrying companies opened new pits in these outlying regions to replace their exhausted city sites. Most, however, were eventually incorporated into larger corporations such as the Consumer Company (the forerunner to Vulcan Materials) and Material Service Corporation founded by the Crown family in 1919.

Unfortunately, urban expansion now threatens even these outlying quarries, jeopardizing the future of the entire Chicago area stone industry (Mikulic and Goodwin, 1986). Although stone reserves are adequate to meet Chicago's immediate needs, additional sources of crushed stone must be found as potential new quarry sites near the city are nonexistent. Underground mining of Ordovician carbonate rocks at existing quarries, as had been done for a time at the Elmhurst-Chicago Stone Company's quarry in Elmhurst, may provide a solution to this problem (Mikulic, 1990).

History of Geologic Research

Research on the geology and paleontology of the Silurian rocks in northeastern Illinois has been rather sporadic. Following a brief burst of activity in the 1860s, research lagged far behind that of surrounding states until the 1920s. Despite this slow start, however, the Racine Dolomite reefs of the Chicago region came to figure prominently in studies of midwestern Silurian geology and Paleozoic reefs.

Paleontology The abundance and diversity of fossils in these reefs initially drew the attention of both amateur and professional geologists to the Silurian rocks of the area in the mid-1800s. The age of these rocks and their correlation with the North American reference section described in New York were soon determined (Worthen, 1862). Formal description of local fossils got underway in the 1860s at a time when few other midwestern fossils had been described, and the race to name new fossils from this virgin territory pitted the eminent paleontologist James Hall of New York against two "local boys," Oliver Marcy and Alexander Winchell, in a dispute over taxonomic priority (Hall, 1865; Winchell and Marcy, 1865).

Interest in Chicago fossils remained high throughout the late nineteenth century as a result of the large collections assembled by wealthy businessmen, or "gentlemen naturalists," with the money to buy fossils and the leisure time to collect specimens. The small, hand-operated quarries of those days were ideal fossil collecting sites, and the low-paid quarry workers were quickly transformed into enthusiastic "paleontologists" when they realized the lucrative market for fossils. Thomas Greene, a Milwaukee druggist, assembled the largest collection of Chicago Silurian reef fossils (Mikulic, 1983), which is now housed in the Greene Memorial Museum on the University of Wisconsin-Milwaukee campus. In 1993, the museum and collection together were named a National Historic Landmark in the History of Science because they are the only remaining intact example of the once-commonplace amateur naturalist collections that played an important role in nineteenth-century American science. For ten years, Greene bought Chicago fossils from one A. G. Warner, who apparently earned all or part of his income by purchasing fossils from quarry men and selling them to wealthy collectors.

Among other prominent collectors of the day were William Egan, whose collection is now housed at the Chicago Academy of Science (Ball and Greacen, 1946), Sir William Van Horne, W. R. Head, G. H. Harris (collections in the Field Museum), and H. H. Hindshaw. Specimens from Chicago reefs also are located in many other museums in North America and Europe. Among the many renowned paleontologists who studied the prolific Chicago fossils were James Hall, S. A. Miller, J. M. Clarke, Stuart Weller, A. F. Foerste, F. A. Meek, A. H. Worthen, P. E. Raymond, Frank Springer, and Charles Wachsmuth. In spite of this early attention, however, the entire reef biota has not yet been described formally, and few taxonomic descriptions have been published since the 1930s. Most fossil groups are in need of revision but only the trilobites and cephalopods are presently under study.

Stratigraphy and Reef Structure While the fossils received intensive study during the late 1800s, little advancement in knowledge about the general geology of the Silurian rocks was made until the 1920s. As the quarries were deepened, a better understanding of regional Silurian stratigraphy emerged and, in 1926, Savage was able to subdivide the rocks into the basic units still recognized today. His classification was refined by Willman in 1973.

The interpretation of Chicago area reefs has changed dramatically through time. Although these highly fossiliferous rocks had been quarried and collected extensively, they were not recognized as reefs until more than 50 years after Hall (1862) first identified reefs in the Silurian rocks of Wisconsin. Apparently a flank-to-core transition was nowhere exposed in the Chicago area, and the steep dips of the flank strata were attributed to tectonism. Although T. C. Chamberlin had inspired renewed interest in the Quaternary and Silurian geology of the Chicago region around the turn-of-the-century, the reefs were studied mainly in their role as islands and shoals in Quaternary lakes. It was not until the 1920s that the true reefal nature of these structures was finally recognized.

Reef Paleoecology Perhaps the most widely known of Chicago Silurian investigations are the paleoecologic studies of the Racine Dolomite reef and interreef strata by Heinz Lowenstam (1942, 1948, 1950, 1957). Because of this work, Lowenstam (1942, 1948) was able to explain the seemingly anomalous presence of supposed Silurian southern faunal elements in a northern faunal province of the Midwest, concluding that it reflected ecologic, not geographic, distribution. He discovered that taxa of the presumed northern province were actually found only in the well-studied reefs, whereas the supposed southern fauna was confined to the poorly exposed interreef strata that surround, and are penecontemporaneous with, the reefs.

Lowenstam's studies of Thornton and other reef exposures coincided with his discovery of subsurface Silurian reefs in the Illinois Basin. Integrating both surface and subsurface data, Lowenstam (1949, 1950, 1957) formulated a model of fossil reef development and paleoecology. In so doing, he was able to relate a variety of separate, superficially unrelated, reef exposures within his three-stage succession of reef development. Lowenstam's paleoecologic work encouraged the study of Silurian and other fossil reefs, and Thornton reef remained the focus for many of these studies (Ingels, 1963; Pray, 1976; McGovney, 1978). Although many Chicago Silurian exposures have disappeared over the years, expansion of the Thornton quarry and the availability of new subsurface data secure the importance of Chicago reefs in future research.

REEF LOCALITIES

Bridgeport

Location NE1/4, SE1/4, Section 29, T. 39 N., R. 14 E., Englewood 7.5-minute quadrangle, Chicago, Cook County, Illinois. The quarry is bounded by South Halsted Street on the east, West 29th Street on the south, South Poplar Avenue on the west, and West 27th Street on the north (Fig. 3). Bedrock elevation is 590 feet (181 m).

Geology and Research History The Bridgeport quarry was excavated to a depth of about 350 feet (107 m), exposing nearly the entire Silurian section. The west, south and east walls have since been covered with landfill, and the lower half of the quarry has been buried (Fig. 4). In the early 1970s, the Metropolitan Water Reclamation District of Greater Chicago (MWRDGC) drilled two cores in the area as part of geotechnical studies for the Tunnel and Reservoir Plan (TARP). Core DH74-53 was located about one and one-half blocks south of the quarry and DH74-26 about three blocks north (Figs. 3, 5). Both cores show the same section that was exposed in the quarry; however, the bedrock surface at the cores sites is at a lower elevation than in the quarry, and the Wilhelmi Formation appears to thicken from north to south.

At present, the top of Brandon Bridge Member of the Joliet Dolomite is the lowest unit still visible in the Bridgeport quarry. Before filling began, a normal sequence of Wilhelmi, Elwood, Kankakee, and Brandon Bridge was exposed, including a prominent bentonite near the middle of the Kankakee. The Brandon Bridge is overlain by 19 feet (6 m) of typical light gray, well-bedded Markgraf Member of the Joliet Dolomite. Overlying the Markgraf and composing the rest of the quarry wall is about 220 feet (68 m) of porous, crystalline, rough-textured, massive- to thick-bedded, reef-like dolomite. Although the Romeo Member of the Joliet and the Sugar Run Dolomite may be present at the base of this interval, they cannot be distinguished lithologically from overlying Racine Dolomite and are therefore included within the Racine here.

At Bridgeport, no typical Racine Dolomite interreef strata (well-bedded, argillaceous, locally cherty) occur. Moreover, distinct reef bodies and associated steeply dipping reef flank strata, prominent at other locations, are insignificant here. Most of the Racine at Bridgeport consists of massive, fossiliferous,

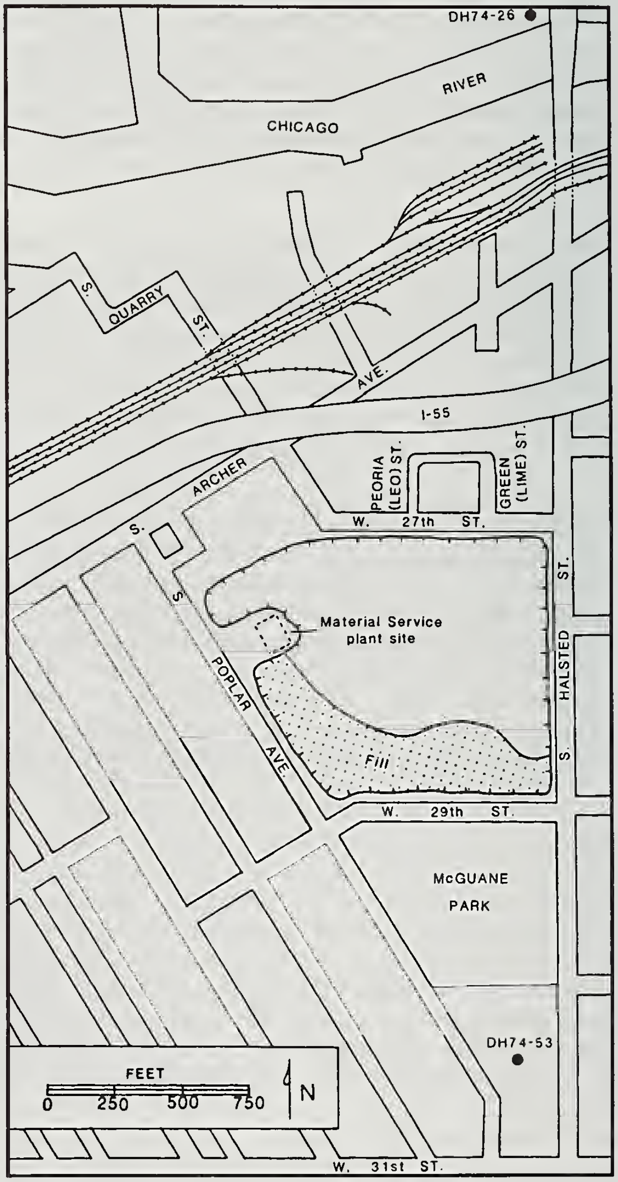


Figure 3 Map of Bridgeport (Stearns) quarry and vicinity. Stippling shows approximate area of quarry filled to ground level as of 1985. Landfill slopes down from this area, filling the bottom 100 feet (31 m) of the entire quarry. Filled circles mark location of MWRDGC cores. Note change in quarry-related street names (e.g., Stearns to 29th Street, Lime to Green Street, Quarry to Senour St.).

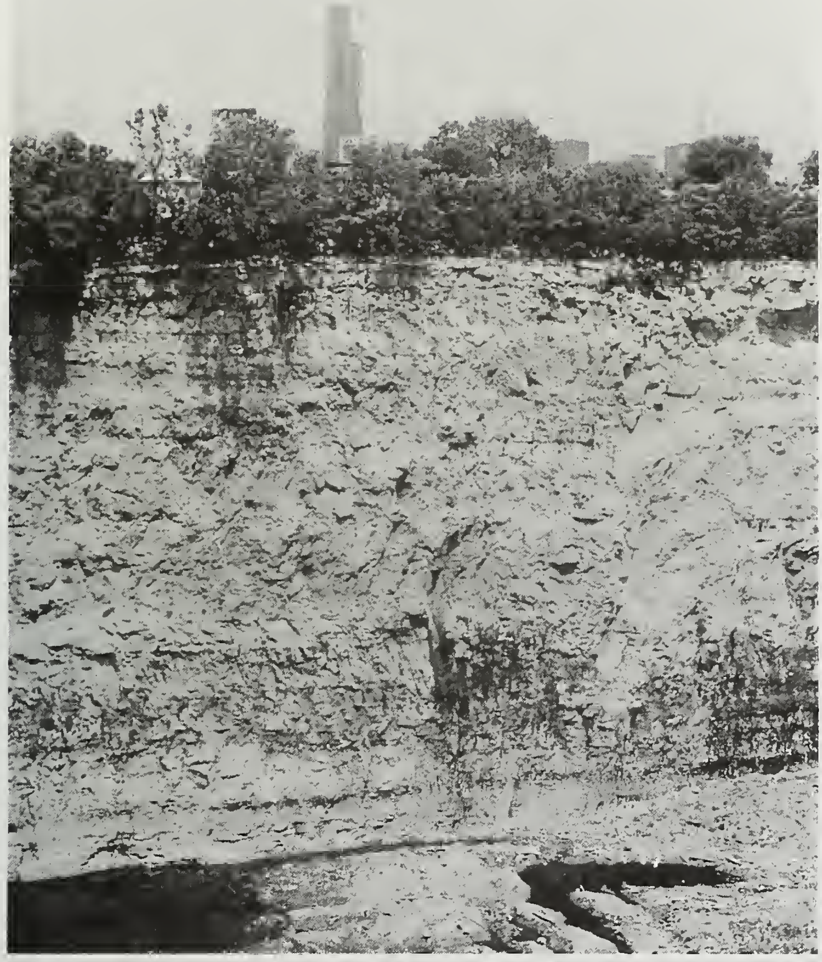


Figure 4 Eastern half of the 260 foot-high (78 m) north wall at the Bridgeport quarry, as it appeared in 1985. At base of the visible section is 22 feet (7 m) of the Brandon Bridge Member of the Joliet Dolomite, the top of which is marked by a thin dark bed. Nineteen feet (6 m) of lighter colored, well-bedded Markgraf Member succeeds this. The remainder of the section is reef-like rock, predominantly Racine Dolomite. Slightly dipping flank strata are visible in about the upper 30 feet (9 m) of the wall. Sears tower (in center background) is located about 2.5 miles (4 km) to the north in downtown Chicago.

reef-like dolomite with only a few obscure horizontal bedding planes or weakly defined beds that may be traced around the quarry. Minor flank development can be seen only in the uppermost 30 feet (9 m) or so of the north wall and the center of the east wall (Fig. 4). It is likely that the Racine Dolomite exposed at Bridgeport represents part of a carbonate bank that was situated along the western edge of the proto-Michigan basin, and only minor local reef growth occurred.

Throughout much of the Racine at Bridgeport, the biota is of limited diversity, comprising primarily pelmatozoan skeletal elements within massive packstones and grainstones. In contrast, the upper 30 feet (9 m) of the Racine here contains a highly prolific and diverse biota. The high diversity pelmatozoan fauna at Bridgeport differs from the limited pelmatozoan fauna at Thornton and Stony Island reefs. In addition, some of the trilobite species, including *Bumastus transversalis, B. (Cybantyx) harrisi,* and *B. (Litotyx) armata,* may be endemic to the reef at Bridgeport. On the other hand, *Bumastus (Cybantyx) insignis* and *B. (Cybantyx) chicagoensis,* two related trilobites that are common in all other northeastern Illinois reefs, are absent or rare at Bridgeport.

With the exception of the Hawthorne quarry (Fig. 2), few other Chicago area sites have yielded as many fossils as Bridgeport, and the great abundance and diversity of fossils attracted many amateur and professional geologists here during the late 1800s. The three largest collections of Bridgeport fossils are the Greene collection (Greene Memorial Museum, University of Wisconsin-Milwaukee), the Egan collection (Chicago Academy of Science), and the Head collection (Field Museum). Worthen (1862) was the first to describe the geology and paleontology of Bridgeport, correlating the strata here with outcrops at Port Byron in western Illinois and assigning them to the Niagara Group of New York. Winchell and Marcy (1865) recorded 82 fossil taxa from this quarry, mostly collected by Marcy, a professor at Northwestern University. Taxonomic fossil descriptions continued to be published until the 1930s, but very little was written about the geology at Bridgeport. Bannister (1868) observed that the rock was *"massive concretionary limestone showing little appearance of stratification,"* and noted that it was very fossiliferous, and Bretz (1939) mentioned the reef structure near the top of the east wall.

Economic History The community of Bridgeport is one of Chicago's oldest neighborhoods, settled in the 1830s by Irish laborers who came to work on the construction of the Illinois and Michigan Canal (Holt and Pacyga, 1979). This site was name "Bridgeport" because cargo had to be unloaded from vessels so they could pass beneath a low bridge that formerly spanned the Chicago River here. As the home of the late Richard J. Daley and several other Chicago mayors (including the present one until very recently), Bridgeport has had considerable impact on Chicago politics.

The quarry at Bridgeport was the first opened in the Chicago area, and it continued to operate long after all other city quarries had closed. Stone production at this site was one of the city's earliest and most prominent pioneer industries. Initial construction of the piers at the mouth of the Chicago River required a large amount of stone which, according to early plans, was to be shipped from Wisconsin's Door Peninsula. Discovery of stone at Bridgeport adjacent to the South Branch of the Chicago River, however, provided a cheaper local source of this material. In 1833, a contract was awarded to Bayer and Spence to quarry stone here and ship it by barge four miles down-river to the site of pier construction. The government provided the barges and eventually built a wooden tramway from the quarry to the river. The quarry site was on land that was to be sold to generate funds for construction of the Illinois and Michigan Canal, but anyone could quarry stone there for pier construction as far as the federal government was concerned. A few years later, however, the State of Illinois protested the exploitation of any natural resource on its canal land without receiving compensation, and the free use of stone ended.

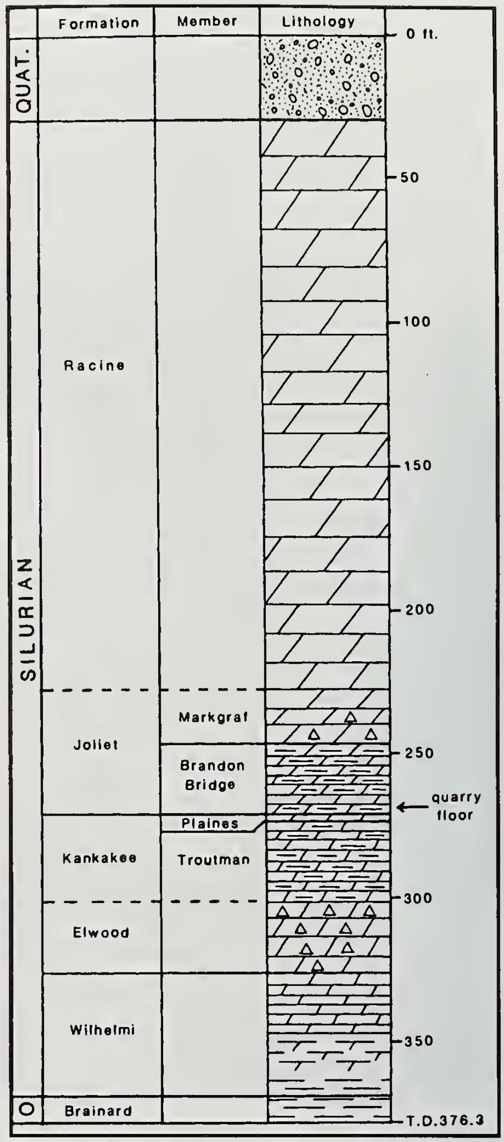


Figure 5 Section of Ordovician and Silurian rocks penetrated by MWRDGC core DH74-53 (elev. 594 ft.) located one and one-half blocks south of the Bridgeport quarry (Fig. 3). Silurian section is identical to that formerly exposed in the quarry, however, the bedrock surface at the quarry is 20 feet (6 m) higher (elev. 590 ft.). Arrow indicates level to which quarry had been filled by 1985. Quat.=Quaternary, O=Ordovician.

Stone for pier construction was probably the chief product at the Bridgeport quarry for most of the 1830s, but in 1839 Reed Lewis and Lansing Hill burned lime at the site. In 1844, Samuel Davis purchased the quarry site and produced lime there until his death in 1848, after which Lewis Stone owned it for a short time. The 1850 federal census records that lime-burning was done at Bridgeport by A. S. Sherman, a future Chicago mayor, and Noah Sturtevant, a prominent lime-dealer who also operated the Hawthorne quarry and lime works in the 1850s-60s. The Bridgeport quarry and lime kiln and the Sherman building stone quarry at Lemont were combined into the Illinois Stone and Lime Company, which was formed in December, 1853, with W. S. Gurnee as president (another future Chicago mayor), Marcus Cicero Stearns as secretary and treasurer, and Oren and Alson Sherman as superintendents (Andreas, 1886). In 1854, the company's assets were divided; the Lemont quarry became the Illinois Stone Company, whereas Stearns became the sole proprietor of the Bridgeport quarry, naming it the Stearns Lime and Stone Company (Fig. 6).

In 1936, the Crown family purchased the company, and merged it with the Material Service Corporation in 1947. By the 1960s, the quarry was surrounded by residential neighborhoods and had been excavated as deep as possible. Among the uses proposed for the mined-out quarry were several creative ones, including an atomic bomb shelter (*Chicago American,* Nov. 10, 1961), cliff-hanging apartments *a la* Mesa Verde (*Esquire,* June, 1968), a sports complex with ample underground parking, and a sewerage system overflow reservoir for the MWRDGC. The quarry was finally sold to the City of Chicago for $9 million on December 31, 1970, for use as a landfill site, the ultimate fate of most other area quarries.

Figure 6 East wall of Stearns Lime and Stone Company quarry. Rock was loaded by hand into quarry cars, which were then pushed along tracks to the base of the incline in the lower left corner of photo. Cars were then pulled by cable up the incline to the kilns. (Photo taken in 1907 by E. F. Burchard, No. 436; Courtesy of the U. S. Geological Survey)

Stony Island

Location S1/2, Section 1, T. 37 N., R. 14 E., and W1/2, Section 6, T. 37 N., R. 15 E., Lake Calumet 7.5-minute quadrangle, Chicago, Cook County, Illinois. Located north of Lake Calumet in southeastern Chicago, Stony Island is bounded by South Stony Island Avenue on the west, by East 91st Street on the north, by South Kingston Avenue on the east, and by East 94th Street on the south. Maximum bedrock elevation is 605 feet (182 m).

Geology Stony Island was a prominent, pre-settlement, physiographic landmark. The "island" portion of its name undoubtedly refers to the fact that this heavily wooded, large reef-controlled bedrock hill once stood conspicuously above the surrounding low swampy land. It actually was an island in glacial Lake Nipissing, however. "Stony" alludes to either the extensive bedrock exposures or the prominent glacial erratics that were once present. The surrounding neighborhood is now known as Calumet Heights in reference to the proximity of this hill to the Lake Calumet area. More recently, the hill has also been called "Pill Hill" because South Chicago Community Hospital is situated on its eastern edge.

At one time, Stony Island was one of the most important and well known geologic sites in Cook County. Displaying a unique combination of reef, glacial and lake erosion features, it was used for both research and education by the University of Chicago and many other institutions in the early 1900s. By that time, the eastern half of the hill had been largely built over and all the trees had long been cut down, but unique biologic features remained and small abandoned quarries and natural outcrops provided excellent bedrock exposures. In 1917, Zonia Baber of the University of Chicago School of Education wrote a guide to the natural features of Stony Island. She proposed that at least the western portion of the hill be preserved for both its geological and botanical features. Later, a bill to preserve the West quarry (Fig. 7) and the surrounding 15 acres as a state park failed in the Illinois State Legislature. Since then, most of the exposures have been destroyed by urban expansion, but a few important geologic features of Stony Island can still be seen.

Although now obscured by residential development, Stony Island still exhibits topographic relief, rising about 25 feet (8 m) above the surrounding Chicago Lake Plain (Fig. 8). The hill has an elongate outline with an east-west length of 1.2 miles (1.9 km) and a north-south width of 0.4 mile (0.6 km). Prior to urbanization, the top of the hill was partly covered by thin glacial and lake sediments, and bedrock was exposed nearly continuously around its periphery (Alden 1902; Bretz, 1943). These outcrops were supplemented by three small nineteenth-century quarries (Fig. 8).

The unique geological features of Stony Island received little attention until the 1890s. At that time, T. C. Chamberlin, then head of the University of Chicago Geology Department and the U. S. Geological Survey Glacial Division, supervised several studies on the Quaternary geology of the Chicago area, including Stony Island (Leverett, 1897; Salisbury and Alden, 1899; Alden, 1902). Owing to its superior erosion resistance, Stony Island almost certainly was a bedrock hill during the final glacial advance through the area. At this time, the top of the hill was planed, with striations on the bedrock surface indicating that the ice flowed around and over the hill from the northeast. Examples of ice flow around small-scale irregularities on the bedrock surface were once visible in the South quarry where a 6 foot-high (2 m) escarpment showed striations at its top, face and under a slight overhang (Leverett, 1897; Alden, 1902). When glacial lake waters were at Toleston level, Stony Island formed a low island (Alden, 1902). Prior shoaling had removed most unconsolidated sedi-

Figure 7 Reef flank strata dipping 42° northwest at the water-filled West quarry, Stony Island (see Fig. 8). View is looking north from near the present corner of East 92nd Place and East End Avenue. (Photo taken in 1939 by Vaillancourt; courtesy of the Milwaukee Public Museum, No. 422841)

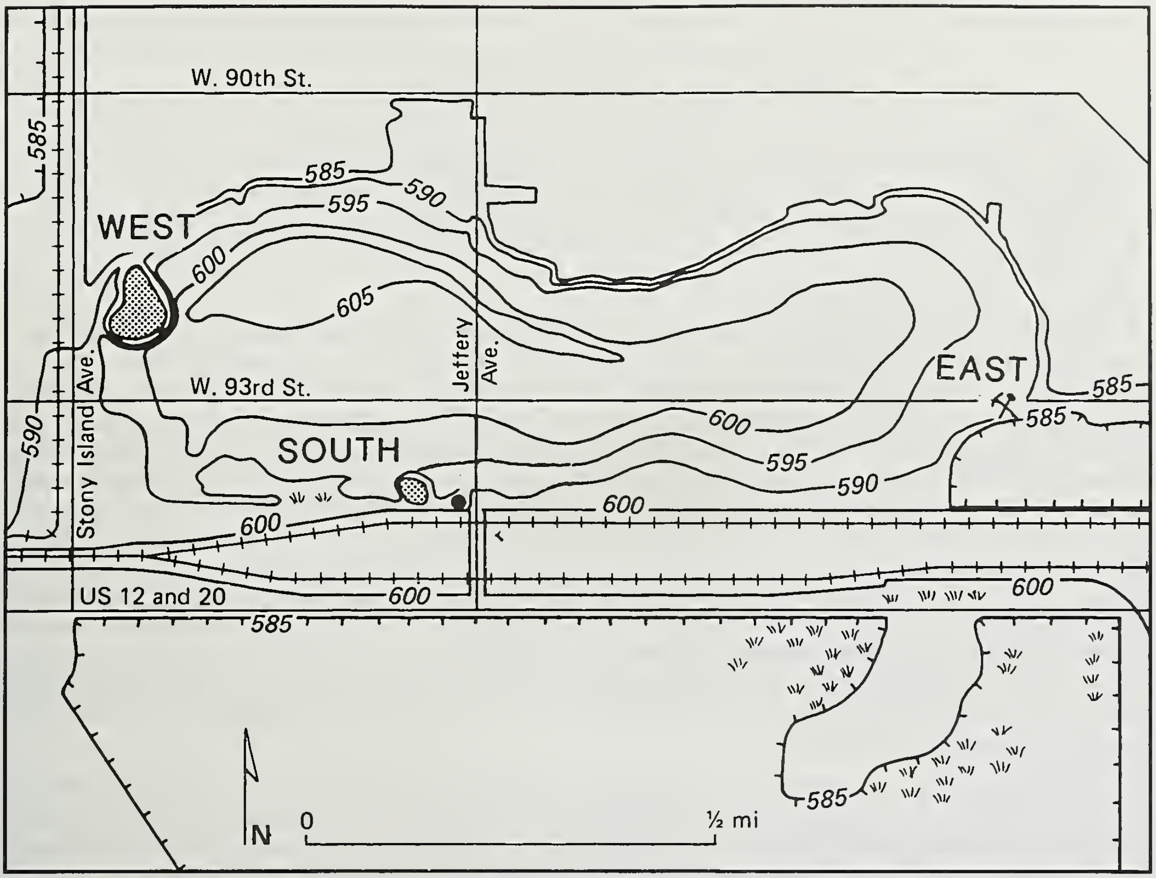


Figure 8 Map of Stony Island showing topography and location of the now-covered West, South and East quarries. Filled circle marks location of outcrop on Jeffrey Avenue. (Redrawn from 1929 Calumet Lake 7.5-minute quadrangle)

ments from the top of the hill (Bretz, 1939) and only large glacial erratics, which were common on the crest of the hill before urban development, remained (Baber, 1917; Bretz, 1939). As the island became more emergent, sand bars developed along its crest (Baber, 1917; Bretz, 1939, 1943). Further erosion removed Quaternary sediments at its margin, leaving behind an almost continuous bedrock outcrop around its periphery.

The exposures and quarries revealed strata dipping radially off the "center" of the hill at 25° to 47°, with the existing outline and surface morphology of the hill generally corresponding to strike and dip (Doggett, 1925). Whereas the glacial and lake features of Stony Island had been deciphered, the origin of these steeply dipping Silurian strata remained controversial. They had been attributed in part to tectonic folding but, by the 1920s, J Harlan Bretz and Rollin Chamberlin had determined their reefal origin (Elwood Atherton, personal communication, 1984). Stony Island is now recognized as a truncated Racine Dolomite reef, the present outline of which probably conforms to original reef morphology. The outline of only a few other Silurian reefs, such as Thornton, have been determined; these are generally more elliptical compared to the "dumbbell" shape of Stony Island. Lowenstam (1950) suggested that the unusual configuration of Stony Island may have resulted from coalescence of two reefs.

The general appearance of the rock varies from the reef center out to its border. Doggett (1925) reported that water main excavations *"a few blocks west of the center of the hill"* uncovered very coarse, highly fossiliferous, massive reef core rock containing small cavities. Nearby, in the north wall of the South quarry (Fig. 8) she found rough and coarse-textured, very irregularly-bedded rock grading into fine-grained, well-defined but somewhat irregularly-bedded dolomite. The latter rock type was typical of exposures in the West quarry and elsewhere along the periphery of the reef. Willman (1943) described the West quarry as being 10 feet (3 m) deep, exposing six inch- to 1.5 foot-thick *"conglomeratic or brecciated"* beds, the former containing *"a few one-half to two inch pebbles of dense fine-grained slightly argillaceous dolomite."* Lowenstam (1950) observed that Stony Island was very similar to Thornton both paleontologically and lithologically. In both reefs, he found flank strata indicative of the high-energy stage of reef development, which was composed of corals, stromatoporoids, and other fossil debris, associated with dense rock containing "streaks" of fossil debris. He also reported reef flank strata interfingering with argillaceous quiet-water interreef strata in the West quarry.

Rock now crops out in only two small exposures, both in the south-central portion of the hill. The best outcrop is a low roadcut on the west side of South Jeffrey Avenue, just north of East 94th Street (Fig. 8). Here, the rock is thick-bedded, porous to vuggy, yellowish gray dolomite that appears to grade upward into dense, nonporous rock. Beds are well-defined, dip 32° southeast, and vugs and biomoldic porosity are locally filled with asphalt. This outcrop is very badly weathered and fossils are not obvious; nevertheless, corals, stromatoporoids, bryozoans and pelmatozoans are present. About one block west is the location of the now-filled South quarry. A very low cut extends west from here along the north side of the Belt Railway of Chicago tracks (between South Euclid and South Bennett Avenues, extended). A few exposures at the bedrock surface occur a short distance north of the cut. The cut reveals thick-bedded flank strata dipping 25° southeast and containing a diverse fauna. The corals *Favosites* and *"Amplexus"* are common, as is pelmatozoan debris. Large gastropods, a variety of brachiopods including *Kirkidium,* and bryozoans also occur. Only a few small fossil collections from Stony Island exist. The Field Museum has specimens collected for University of Chicago research and class field trips, and the Greene Memorial Museum has a few specimens collected in the 1880s.

The reefs at Stony Island and Thornton are very similar to one another but differ significantly from the reefs at Bridgeport and Hawthorne. Stony Island and Thornton are characterized by the volumetric dominance of steeply dipping flank strata. The biota of both reefs is dominated by corals, stromatoporoids, gastropods and brachiopods. Pelmatozoan debris is common as grains, but large diameter, partially articulated stems are rare in the flank strata, and pelmatozoan diversity is significantly lower than at Bridgeport and Hawthorne. Stony Island, like Thornton, was a fossil hydrocarbon reservoir, but it may differ in its lack of satellite reefs, megaclasts and *Kirkidium*-rich beds. Their absence may reflect limited exposures, however.

No cores have been drilled on Stony Island, therefore, little is known about its subsurface characteristics. However, MWRDGC cores within one or two miles of the hill indicate that Silurian rocks are about 360-400 feet (111-123 m) thick locally where reefs are absent. (Thickness varies because of erosion, the eastward dip of Paleozoic rocks, and the thickness of underlying Maquoketa strata.) Nearly all of the Upper Ordovician Brainard Formation in the area was removed by pre-Silurian erosion, resulting in a thick (100 ft., 31 m) lower Silurian section (Wilhelmi, Elwood, Kankakee formations). On the basis of soil boring records and seismic survey profiles run for the MWRDGC, the Stony Island reef is known to rise 70 feet (22 m) above the surrounding bedrock surface. These data suggest that the Silurian at Stony Island is nearly 500 feet (154 m) thick. If it is assumed that Stony Island reef development began during deposition of the basal Racine Dolomite, as did the nearby smaller Torrence Avenue reef, then the reef itself is probably at least 330 feet (102 m) thick (Fig. 2).

The Torrence Avenue reef is located about 1.5 miles (2.4 km) south of Stony Island along Torrence Avenue between South 106th and 109th Streets (Fig. 2), and is known only from MWRDGC cores (Keifer and Associates, 1976). The Silurian is about 470 feet (145 m) thick at this site, and bedrock comes to within about 20 feet (6 m) of the ground surface. Extending from about 1.4 to 2.5 miles (2.2-4.0 km) northeast of Stony Island is the Cheltenham reef, which formerly was exposed in small outcrops and quarries (Fig. 2). Little is known about this reef, although temporary exposures in the vicinity have recently uncovered dominantly pelmatozoan-rich grainstone with asphalt-filled vugs and pores. A few fossils collected from this reef during the 1880s are preserved in the Greene Museum. Other reefs occur as shoals farther east in Lake Michigan (Bretz, 1939).

Economic History The quarry history at Stony Island is poorly known. Bannister (1868) was the first to mention a quarry at this site, and it is known that Dolese and Shepard Company operated at least one quarry there at a later date (Andreas, 1886). No lime kilns were mentioned in the early descriptions, and it is likely that only crushed stone was produced at the time the quarries closed. Some rock, however, may have been used for flux in the rolling mills at nearby South Chicago. An unpublished letter dated June 30, 1886, from A. G. Warner to T. A. Greene states that two Stony Island quarries had recently been abandoned, and that operations had started up near Cheltenham Beach. The largest Cheltenham quarry was located at West 82nd Street and South Houston Avenue where the Cheltenham Stone and Gravel Company was operated by F. A. Meeker in the mid-1880s. Dolese and Shepard ran this quarry for a few years prior to 1890, but it was closed permanently shortly thereafter. Although Stony Island was an excellent quarry site, there is no indication that any stone was quarried there after 1886. By the turn-of-the-century, housing construction eliminated the possibility of quarrying on the east side of the hill. Much of the western half of the hill remained undeveloped until the quarries were filled in the 1940s and early 1950s.

Thornton

Location SW1/4, Section 27; all of Section 28 except NW1/4; E1/2, SE1/4, Section 29, and N1/2, Section 33, T. 36 N., R. 14 E., Calumet City and Harvey 7.5-minute quadrangles, Thornton Township, Cook County, Illinois (Fig. 9).

Economic History Quarrying has long been the major industry in Thornton. Taking advantage of the thin overburden and high-quality rock, settlers opened a number of small quarries here in the early 1800s to produce lime and building stone. Some of this stone can still be seen in foundations of many of the pre-1900 buildings remaining in Thornton. The precise history of these early operations is not recorded but, reportedly, the first quarry was opened in the late 1830s for Gurdon Hubbard, a prominent pioneer settler of the Chicago area (Andreas, 1884). This may have been the now-filled quarry located in a park on Kinzie Street between Harriet and Eleanor Streets (Fig. 10). By 1850, Stephen Crary had also opened a quarry, and through the 1860s, a number of individuals, including Daniel Dickel, Case and Sweet, Lot Chapman, as well as the Hews Stone Company, were listed as lime dealers in business directories and censuses. The 1870 federal census lists Rollin Flanagan, Lot Chapman, Elias Daniel, and Joseph Kotlunek as operating quarries or burning lime at Thornton. By the 1880s, Flanagan was the largest quarry operator, producing as much as 800 cords of stone in 1882 (Andreas, 1884). Flanagan's quarry was located just west of the current Material Service plant in what is now the South Pit. Apparently, Flanagan produced only crushed stone here while Daniel Dickel burned lime nearby. In about 1888, Fred and Ira Gardner began operating a lime kiln and quarry at the corner of Wolcott and Juliette Streets.

In 1886, Flanagan's holdings were sold to Ralph E. Brownell, a Chicago civil engineer. Brownell and his partners increased production to meet the demand for crushed stone, which was then being used primarily for macadamizing Chicago area streets and as ballast for railroad track beds. The Brownell name would be associated with Thornton's quarries for more than 50 years, although ownership of the company changed hands throughout this interval. In 1888, it was known as R. E. Brownell and Company, but by 1891 it had become the Eggleston, Mallette and Brownell Stone Works. In 1895, it was called the Brownell Improvement Company, which merged the next year with the Chicago-based Kimbell and Cobb Stone Company. Jefferson Hodgkins of Kimbell and Cobb became president of the firm with R. E. Brownell as vice president and Spencer Kimbell as treasurer. Over the next several decades, the Brownell Improvement Company, under the direction of Hodgkins and, later, his son William, developed into a major Chicago area stone producer.

By 1907, the main Brownell quarry was about 85 feet deep and covered ten acres (Fig. 11). At that time, the company decided it would be cheaper to operate at a shallower depth, and opened a new

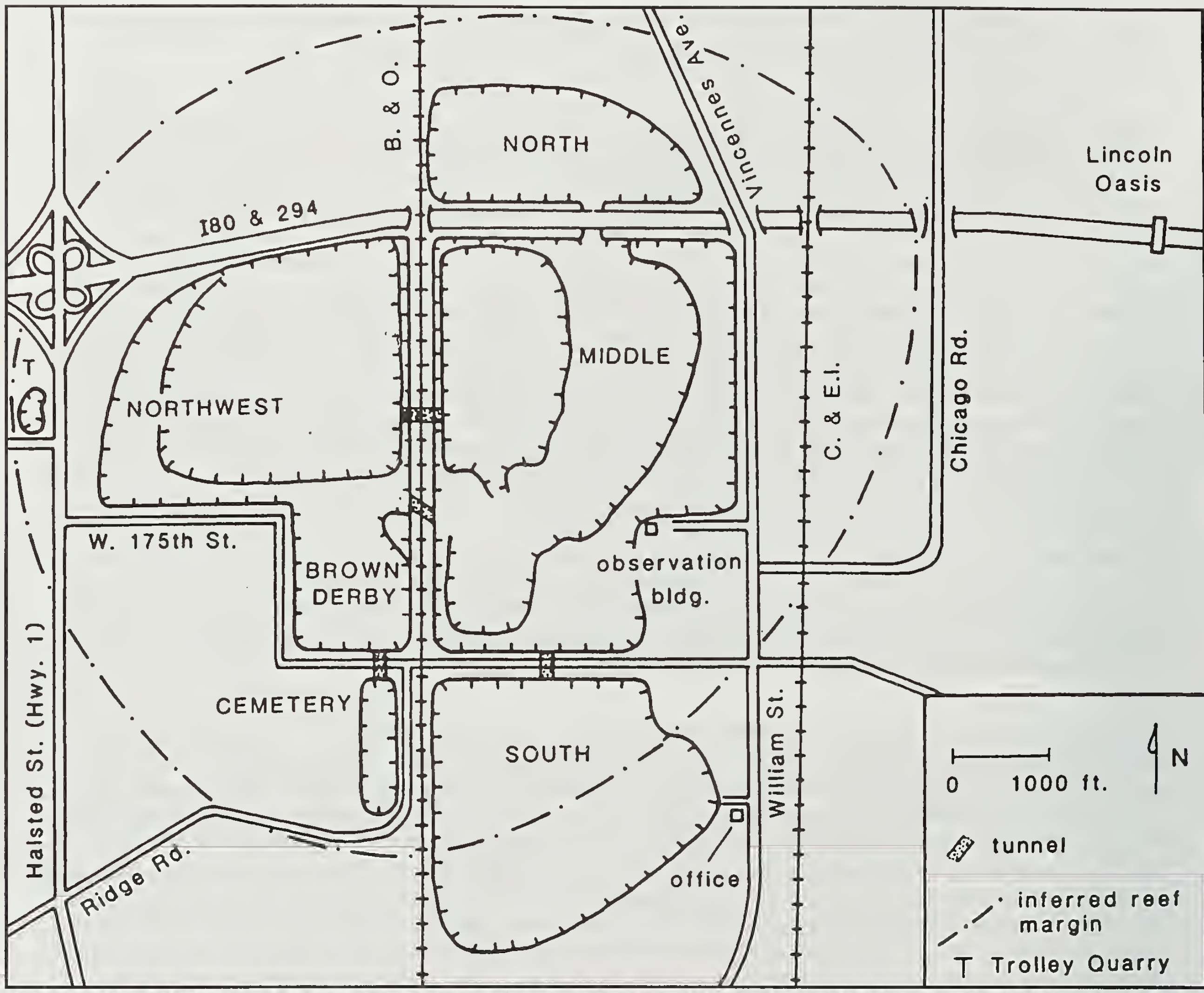


Figure 9 Map of Thornton quarry area showing approximate edge of the reef (modified from Ingels, 1963) and individual quarry pits.

area to the west. A 26 foot-deep, ring-shaped cut was quarried first to facilitate the use of a trackway for haulage cars, and stone was then quarried inward toward the center of the circle.

The senior Hodgkins has been linked with several innovations in the quarrying industry. He is credited as being one of the first operators to use a steam shovel (a Bucyrus) to load quarry dump-cars—a formidable task previously done by hand. In 1910, he established a stone-washing plant at Thornton—one of the first ever erected. And, after Thornton's crushing plant (c. 1914) was mostly destroyed by fire, he replaced it, in 1917, with the largest crushed-stone plant in the U.S., capable of producing 10,000 tons of stone a day.

On the basis of substantial geological exploration, the Brownell Improvement Company was able to determine that quality stone several hundred feet thick was present over a large area to the west and north of their quarries at Thornton. They, then, acquired much of the land east of the B. & O. railroad tracks and, in 1924, constructed a tunnel under Margaret Street, which allowed them to quarry land to the north (now the Middle Pit).

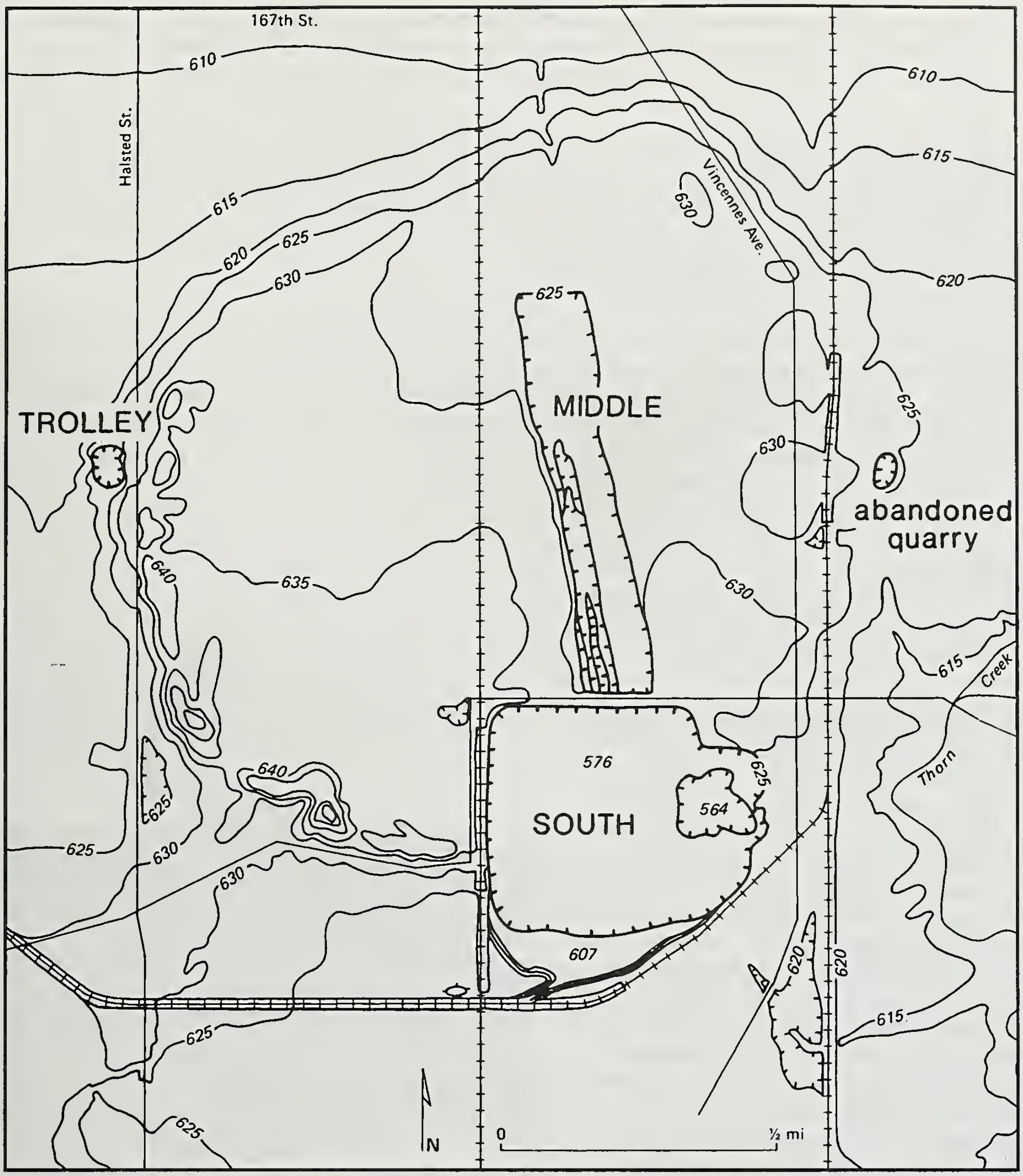


Figure 10 Topographic map of the reef-controlled hill at Thornton, showing the outlines of the North (now Middle) and South quarries of the Brownell Improvement Company, the abandoned Trolley (Interurban) quarry, and the abandoned quarry (possibly Gurdon Hubbard's) now located in Walter Diekelman Park. (Redrawn from 1929 Calumet City and Harvey 7.5-minute quadrangles)

In 1930, the company merged with the Thomas Moulding Brick Company to become Moulding-Brownell Corporation. Business was slow during much of the 1930s owing to the Great Depression, and quarrying ceased permanently in the South Pit around 1936 (John Gulich, personal communication, 1984). In 1938, the company went bankrupt and was operated temporarily by the Thornton Quarries Company. A short time later, it was acquired by the Material Service Corporation, which had been founded as a building supply company in 1919 by Henry, Irving and Sol Crown. The Crown brothers, who began purchasing stone quarries in the 1930s, became one of the largest stone producers in the Midwest. In 1948, Material Service also acquired the Marblehead Lime Company, and opened a new lime plant at Thornton in 1950.

The Crowns maintained the modern quarrying standards established by Hodgkins. In the early 1940s, the old Bucyrus steam shovels at Thornton were replaced by electric shovels, which were used until the 1970s when front-end loaders took their place. During 1957-58, the entire Thornton plant was rebuilt. At this time, the trackways, quarry cars and steam locomotives were replaced by trucks and the long conveyor extending from the Middle Pit to the main plant. The Crowns also implemented a program of expansion and, in the late 1960s, a tunnel was constructed beneath the B. & O. railroad tracks in order to open the Northwest Pit. The Brown Derby Pit was first quarried in 1975, and the Cemetery Pit, which was quarried mainly to serve as a settling pond, operated from 1981 to 1984. For the last several decades, the Thornton quarry has remained one of the ten largest commercial aggregate quarries in the country.

Geology and Research History Thornton Reef forms a low (25 ft., 8 m) hill with a maximum elevation of 635 feet (195 m) above sea level (Alden, 1902; Bretz, 1943) (Fig. 9). For a time, the reef was a shoal in glacial Lake Chicago, rimmed by beach ridges and flanked by sand dunes on its west and south sides (Bretz, 1939). The extant reef, which is elliptical in outline along a northeast-southwest axis, has a maximum length of 1.5 miles (2.4 km). It is thickest (340 feet; 105 m) at its center, reflecting its convex-downward bowl shape (McGovney, 1978). Although the exposed portion of the reef lies entirely within the Racine Dolomite, subsurface data indicate that reef growth began earlier, possibly during deposition of the Joliet Dolomite (Fig. 1).

The reef apparently had little effect on most of the Silurian section beneath the Racine Dolomite. The only exception is the Sugar Run Dolomite as well as the Romeo and Markgraf members of the Joliet Dolomite which, although typical in character lateral to the reef, become indistinct near its center probably as a result of early reef development. The underlying Brandon Bridge Member of the Joliet Dolomite is consistent in its character and thickness (30 feet; 9 m), and is not absent anywhere in the area as indicated by McGovney (1978, 1988). The Brandon Bridge overlies 110 feet (33 m) of a normal succession of Kankakee, Elwood and Wilhelmi formations. The underlying Upper Ordovician Maquoketa Group was deeply eroded throughout most of southeastern Cook County prior to Silurian deposition, and is only about 150 feet (46 m) thick here (Mikulic, 1990).

Figure 11 South wall of Brownell Improvement Company quarry (near center of present South Pit and since removed) showing hoist to steel lime kilns in 1907. About 80 feet (25 m) of interreef strata are visible. Irregular bedding near center of wall may be a megaclast or fore-reef that was located about the same distance from the main reef as features in west wall of present South Pit. (Photo by E. F. Burchard, No. 432, U. S. Geological Survey Library)

Thornton Reef has been important in Silurian reef studies for more than 50 years. Classic works by Bretz (1939), Lowenstam (1948, 1950, 1957), Willman, *et al.* (1950), Lowenstam, *et al.* (1956), and Ingels (1963) were based entirely or in part on Thornton reef, and it continues to be the subject of study as new exposures and subsurface data become available. This research mainly concerns the depositional history of the reef, which has been the focus of much controversy (Pray, 1976; McGovney, 1978, 1988; Mikulic, *et al.*, 1983; Mikulic and Kluessendorf, 1985; Mikulic, 1987). The history of Thornton reef studies and changes in interpretation are tied closely to the progressive development of the quarry. Within the quarry, the order of field trip stops follows this development.

Interstate Roadcut and Trolley (Interurban) Quarry The main route to the Material Service quarry passes two important, but inaccessible, sites that warrant some discussion. The Interstate 80-294 roadcut, which was excavated in the mid-1950s, was first described by Ingels (1963). This extensive exposure allowed him to interpret large portions of the reef that had not been uncovered by quarrying, and supplied basic information for his reef reconstruction. Although it is impossible to examine the roadcut closely, general features can be seen by car **passengers** while passing it. **[It is dangerous and illegal to park or walk along this roadcut.]** The roadcut, which begins west of the Lincoln Oasis at the South Chicago Road overpass on the interstate, transects the northern one-third of the reef through distal flank strata. At the eastern end of the roadcut on the north side of the highway is a 50 foot-long (15 m) exposure of massive dolomite, followed on the west by normal distal flank strata dipping 10° northeast. Several tongues of greenish-gray argillaceous interreef strata occur between here and the C. & E. I. railroad bridge. Near the bridge, dip of the flank strata increases rapidly to 30° northeast. From east to west along this portion of the roadcut, flank strata also change from thin-bedded, dense dolomite with scattered fine biomoldic porosity to thicker-bedded strata containing many lenses and layers of coarse biomoldic porosity. The low angle of dip (10°) and the fine bioclastic debris in this portion of the roadcut was interpreted by Ingels (1963) as representing distal flank beds leeward of the reef. Passing the gap at Material Service quarry, well developed distal flank strata dipping north or northeast are visible in the North Pit. Currently, plans are being developed to use the North Pit as an overflow reservoir for the MWRDGC tunnel and reservoir system and Thorn Creek. Where the roadcut resumes at the B. & O. railroad bridge, flank strata dip 30° north, whereas farther west at the State Highway 1 toll plaza, they dip 45° northwest. Ingels (1963) interpreted this portion of the roadcut as representing distal flank beds along the northwest margin of the reef.

Less than a mile from the toll plaza, on the west side of Halsted Street, is the abandoned Trolley (Interurban) quarry (Fig. 10). This quarry was opened around 1906 to produce ballast for the Chicago and Southern Traction Company, which operated an interurban line extending from Chicago to Kankakee, paralleling Halsted Street in part. The quarry was operated by the Franklin Stone Company (named for the nearby Franklin Station on the interurban line) in 1917, but was abandoned by 1920. In recent years the quarry has been used as a dumpsite and is now nearly filled. Steeply dipping flank strata in this quarry were instrumental in Bretz's (1939) accurate determination of Thornton Reef geometry. In the northeastern corner of this quarry, thin-bedded flank strata dip about 35° northwest (Fig. 12). The rock consists of light gray, dense dolomite with common asphalt-filled biomoldic porosity and lenses of coarse bioclastic debris. A few thin argillaceous strata pinch out downdip. Near the center of the north wall, strata are thicker-bedded, less porous, and contain no argillaceous partings. A few thick beds of conglomerate, comprising abundant flat, rounded pebbles and cobbles in a dolomite matrix, are present. In the southwestern corner, the thick-bedded flanks dip to the west at 50°-60,° possibly representing a displaced megaclast. Small spherical tabulate coral and stromatoporoid colonies and fragments of platy organisms, such as *Heliolites,* are typical of the fauna in this quarry, but large hemispherical colonies common elsewhere in reef flank strata are noticeably absent here. Fine pelmatozoan debris is ubiquitous, and a variety of bryozoans as well as pelmatozoan debris and small stromatoporoid colonies characterize the more argillaceous bedding surfaces. The strata in the Trolley quarry are steeply dipping distal flank beds typical of the windward portion of the reef, contrasting sharply with the low-angle flank strata in the eastern portion of the Interstate roadcut. Interreef strata are absent.

Material Service Quarry The Material Service Corporation quarry together with the Interstate roadcut provides one of the best Paleozoic reef exposures in the world. The quarry walls preserve cross-sections of various portions of the reef through nearly its entire thickness. Supplemented by many cores and more than 60 years of intensive study, Thornton reef is very well known, and has been the focus of numerous geological field trips, dating back to the 1930s.

Figure 12 Steeply dipping distal flank strata in the east half of the north wall of the Trolley (Interurban) quarry (see Fig. 9). (Photo by H. B. Willman, 1942)

The quarry comprises six separate pits: South, Middle, North, Northwest, Brown Derby and Cemetery (Fig. 9). The Cemetery Pit (now inaccessible) was quarried from 1980-1984. With a maximum depth of 140 feet (43 m), this pit exposed mostly distal flank strata dipping 40° south. The reef-interreef transition lies farther south, although a thick tongue of interreef strata extends northward into this pit.

South Pit The main plant for the Material Service quarry is situated on the eastern edge of the South Pit, which is at the southeastern border of the reef (Fig. 9). This is also the site of Flanagan's and Brownell's original plants and quarries. Quarrying was discontinued in the South Pit around 1936 because the section of pure reef rock is thin here and the argillaceous interreef rock is unsuitable for high-quality aggregate. The pit now is used for settling basins and yard operations.

The South Pit exhibits some of the most historically important exposures where many of the earliest geologic interpretations of the reef were made. Because this was the earliest quarried area of the reef, all geologic observations were confined to this pit until the mid-1920s. Until then, all quarrying activity in and around Thornton was situated in interreef or distal reef flank strata. Although the flank strata here were fossiliferous, they did not yield the same diversity and abundance of fossils as other reefs like Hawthorne and Bridgeport. Therefore, Thornton Reef was largely ignored by nineteenth-century collectors and geologists. Although the prominent dip of distal flank strata was apparent to early geologists, it had no clear connection to reef structure and was, consequently, attributed to tectonics (Alden, 1902). In the early 1900s, J Harlan Bretz, Rollin Chamberlin and other University of Chicago geologists began to study Thornton, while using it as a class field trip destination (Pettijohn, 1984). It was during their work that the reefal origin of the structure at Thornton was recognized. Exactly when this was accomplished and by whom was not recorded at the time, but Bretz (1939) explained the rationale used in the determination. Interestingly, some of the first

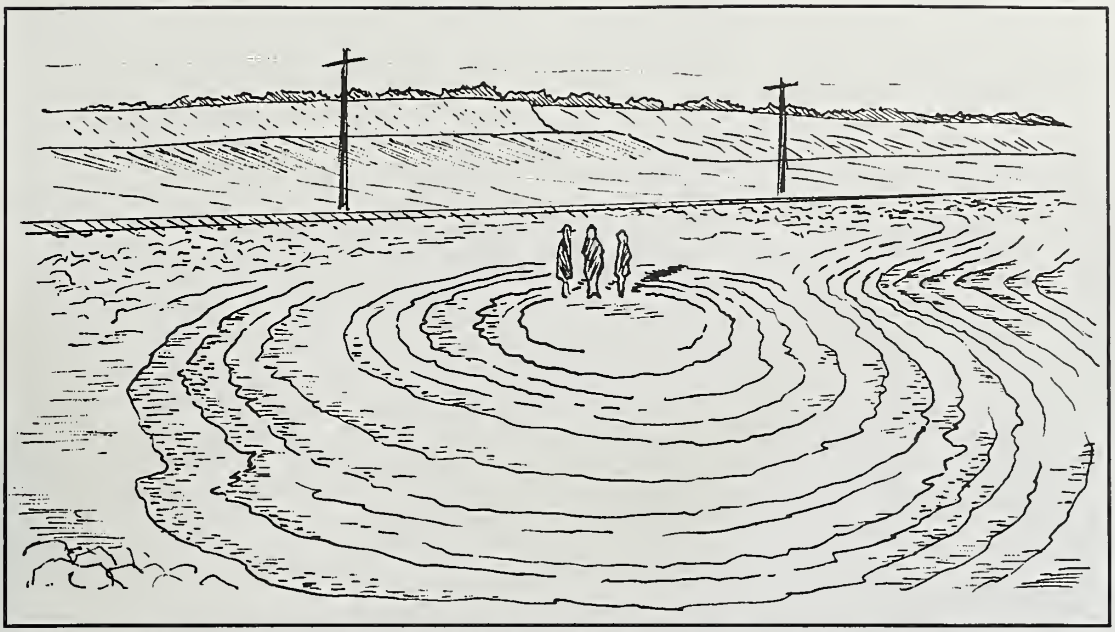


Figure 13 Truncated domed beds overlying a small "reef" in the South Pit at Thornton quarry. (After Fenton, 1931, from a photograph by T. A. Link)

"reefs" described at Thornton (Doggett, 1925; Fenton, 1931) are no longer considered reefs, but rather megaclasts. The earlier interpretation was not inappropriate, however, considering that these features were highly fossiliferous, mounded structures surrounded and overlain by typical, poorly fossiliferous interreef strata (Fig. 13). Furthermore, it was difficult to establish relationships between these structures and surrounding strata in the shallow quarries of the day. Even now, the origin of some of these smaller reef-like bodies is open to debate.

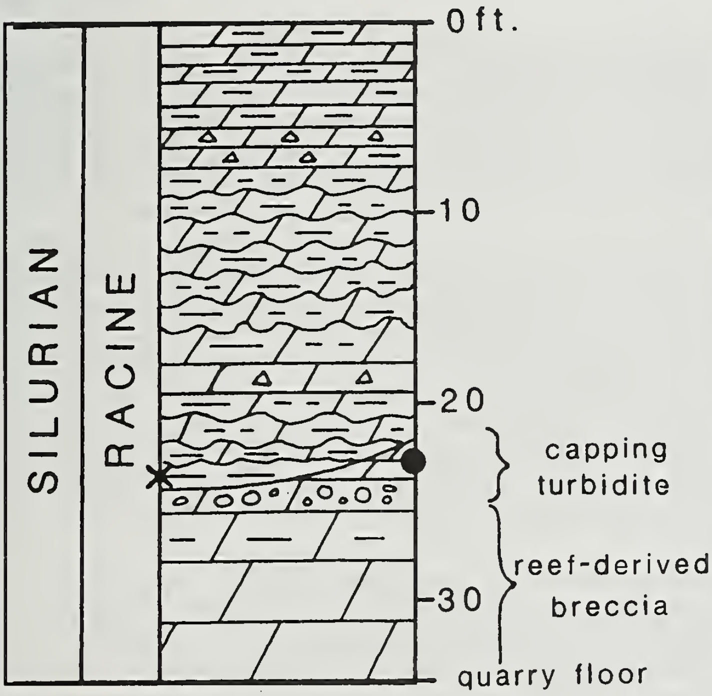


Figure 14 Section of Racine Dolomite interreef strata near center of south wall, South Pit, Thornton quarry. X marks location of sample 8a which yielded the conodont *Kockelella variabilis;* filled circle indicates the location of sample 9a which contained the conodont *Ozarkodina sagitta rhenana* and possibly *O. sagitta bohemica.*

Most walls in the South Pit have been covered, obscuring features such as the reef-interreef contact, which runs diagonally from the center of the west wall to just north of the plant buildings. Interreef strata at Thornton are best exposed in the south wall. These strata are generally thin-bedded, flat-lying, argillaceous to silty dolomite (Fig. 14). Abundant discontinuous wavy argillaceous partings produce nodular strata that make up most of the section. Chert in widely scattered nodules and discontinuous layers occurs primarily in the upper part of the section. Most of the chert was formed prior to, or penecontemporaneous with, dolomitization (Weiner and Koster van Groos, 1976). Grain-supported bioclasts that appear as "ghosts" in the dolomite matrix are well preserved in the chert, revealing the original grainstone fabric of some of the sediments. Patches of fine silicified bioclastic debris and larger coral and stromatoporoid colonies occur locally. Silica for chertification probably was derived from siliceous sponges (Lowenstam, 1948; Weiner and Koster van Gross, 1976).

Bioclasts in the interreef facies are dominated by fine (1 mm) pelmatozoan debris. Less common are fragments of bryozoans, brachiopods, ?ostracodes, trilobites, stromatoporoids, tabulate corals, and sponge spicules. Lowenstam (1948) identified the tabulates *Favosites* and *Halysites*, rare complete siliceous sponges, and the crinoids *Pisocrinus, Myleodactylus,* and *Gissocrinus.* Micrite envelopes enclose some pelmatozoans preserved in the chert, and peloids in the chert may be completely micritized bioclasts. Weiner and Koster van Groos (1976) discovered microscopic spherical algal bodies in the chert. Orthoconic nautiloid cephalopods and calymenid and encrinurine trilobites are also present. Interreef fossils, in general, exhibit a significantly different style of preservation compared to specimens from the reef proper. For example, the interreef cephalopods are compressed and preserve very little ornamentation, whereas in the reef, specimens exhibit little or no compression and external molds commonly preserve fine details (Hewitt, *et al.,* 1987). *Planolites,* which occurs on some bedding surfaces, is the only common ichnotaxon, but bioturbation is ubiquitous in interreef sediments, commonly yielding a mottled or swirled texture and poor sorting of bioclasts, indicating little sediment disruption by physical agents. The argillaceous composition of the sediment, the nature of the biota, the fine size of the bioclasts and the presence of *in situ* organisms further suggest that the interreef strata were deposited under quiet water conditions.

Throughout much of the South Pit, interreef strata overlie a reef-detritus breccia that was first described by Willman, *et al.* (1950). They reported that the breccia ranges from four to ten feet (1.2-3 m) in thickness and is underlain by argillaceous dolomite at least 12 feet (4 m) thick. The breccia consists of granule- to boulder-sized lithoclasts in an argillaceous dolomite matrix. Reef-derived megaclasts as much as 40 feet (12 m) long occur. Smaller clasts are not typical reef lithology, but are dominantly chert or fine-grained dolomite. Bioclasts, particularly pelmatozoan, coral and stromatoporoid fragments, are common in the granule- to pebble-sized fraction.

Although he failed to recognize the brecciated nature of this interval, Bretz (1939) was the first to identify large clasts in the west wall as *"displaced fragments of reef rock"* based on their composition and orientation. Just north of the southwest corner of the South Pit is the most conspicuous reef-derived megaclast, which is 40 feet (12 m) long and 8 feet (3 m) high in its exposed portion and displays sharp irregular contacts with the adjacent breccia (Fig. 15). The megaclast is composed of fossiliferous, medium gray, vuggy dolomite with vugs and pores commonly filled with asphalt. The bedding, which dips 76° north, is defined by alternation of dense and porous layers. Fossils are dominated by stromatoporoids, gastropods and corals, especially *"Amplexus,"* and *Favosites; Halysites* occurs only as rare fragments. Lithologically and paleontologically, this megaclast is identical to proximal flank strata like that exposed in the extant reef. Angular blocks of similar reef rock up to several feet across occur within the breccia for the next 120 feet (37 m) to the north. Most are located south of and beneath Bretz's reef (Fig. 16) (Bretz, 1939, figs. 46, 49). A 10 to 30 inch-thick (25-75 cm) normally-graded bed of pebble- to silt-sized clasts in an argillaceous dolomite matrix thins and thickens over irregularities on the megaclast surface. Bioclasts (pelmatozoans, bryozoans, brachiopods) compose most of the granule- to pebble-sized fraction in this breccia. Parallel laminae, which Pray (1976) interpreted as a *"capping turbidite facies,"* occur locally in the upper few inches of the bed. Normal nodular argillaceous interreef strata overlie the graded bed abruptly.

Two other features in the west wall of the South Pit, the forereef and Bretz's reef, figured prominently in early Thornton studies. The forereef, which is located in the southwest corner about 200 feet (62 m) south of the megaclast, has been covered by fill (See Willman, *et al.,* 1950; Ingels, 1963; and Pray, 1976, for early interpretations of this feature.). Forereef strata consist of massive, gray, vuggy reef rock containing a typical reef fauna dominated by stromatoporoids and corals, especially *"Amplexus"* and *Favosites.* A normally-graded bed that thins and thickens over irregularities at the top of the forereef differs from the "capping turbidite" overlying the megaclast in that it is almost identical in lithology to the top of the forereef and contains coral and stromatoporoid bioclasts. Dips in the interreef strata on the adjacent bedrock surface delineate the domed top of the forereef and

Figure 15 Megaclast of proximal reef flank rock overlain by nodular argillaceous interreef strata near southwest corner of west wall, South Pit, Thornton quarry. "Capping turbidite" occurs at shoulder level of figures in photo (1984).

suggest that it extends farther west. West of the forereef, interreef strata on the bedrock surface define a circular pattern suggesting the presence of another domed structure possibly related to the forereef (see Fig.13 for a similar feature). It is unknown how far east the forereef extended; however, Willman, *et al.* (1950) considered it to be *"a linear feature parallel to the edge of the main reef"* based on *"numerous exposures of massive reef-rock in the quarry floor on a line slightly north of east from the exposure in the west face."*

Bretz's reef, which is located 120 feet (37 m) north of the megaclast, is a massive domed structure that projects above the top of the breccia (Fig. 16). On its north side, interreef strata drape over it, but on the south, lower interreef strata abut against it and upper strata drape over it. The reef surface slopes slightly on the north, but drops off abruptly on the south, forming an overhang about 15 feet (5 m) wide. Dense, almost white, fine-grained dolomite adjacent to this overhang may be sediment trapped in a current shadow zone. The graded cap facies that overlies the megaclast and breccia wedges out against Bretz's reef, but at a higher level on the north than on the south. Below the level of the cap facies, the structure is massive, rubbly and contains few vugs. Above this level, the rock contains common vugs related to coral and stromatoporoid colonies possibly in growth position. Obscure bedding in the structure conforms to the slope of the reef on the north. Many characteristics of this structure suggest it represents in-place reef growth (Bretz, 1939), but McGovney (1978) proposed that it is another megaclast within the breccia. To the north of Bretz's reef are several structures that are probably megaclasts. The reef-interreef contact was exposed farther north, but it now is covered by fill. Typical flank strata compose the remainder of the west wall.

Well-developed reef flank strata dip 35° southeast at the tunnels in the middle of the north wall of the South Pit. Generally, these strata consist of cyclically alternating porous and dense dolomite layers corresponding to original packstone/grainstone and wackestone lithologies. The porous layers apparently grade upward into the dense layers. Bioclasts, which are abundant and poorly sorted in the porous layers, are dominated by corals, stromatoporoids, gastropods and brachiopods; locally some colonies appear to be *in situ*. Isopachous rim cement lines interparticle porosity in the grainstone.

The exposure at the tunnels conveys the problems faced by nineteenth- and early twentieth century geologists in recognizing the reefal nature of such dipping strata in Illinois and Indiana. The small quarries of the time, which were generally only a few tens of feet deep and a few hundred feet across, exposed even less rock than is visible here. All that could be seen was a predominance of uniformly dipping strata, showing no transition to either reef core or interreef strata. Consequently, a structural explanation for these strata was reasonable, especially when taking into account the limited overall knowledge of the general geology of the region. Moreover, the undoubted structural origin of deformed strata in the Kentland Disturbance, which is located so near Indiana and Illinois flank bed exposures, added weight to a possible structural derivation for the dipping reef flanks (see discussion in Gorby, 1886). It was not until the 1920s that Robert Shrock (Cumings and Shrock, 1928) demonstrated that Kentland (now known to be an impact site; Gutschick, 1987) was unrelated to any of the Silurian features, which he correctly identified as reefs (R. R. Shrock, personal communication, 1991).

Because no biostratigraphic data were available previously, Thornton Reef was assigned the assumed age of the Racine Dolomite (Wenlockian through Ludlovian) (Mikulic, *et al.,* 1983). Conodonts, including *Kockelella variabilis, Ozarkodina sagitta rhenana* and *O. sagitta bohemica* (R. D. Norby and T. L. Adams, personal communication, 1985), have since been collected from the south wall of this pit. *Kockelella variabilis* was found in sample 8a from a shaley horizon about 23 feet (7 m) below the top of the south wall (Fig. 14). This species ranges from mid-Wenlockian to late Ludlovian. *Ozarkodina sagitta rhenana* and a possible specimen of *O. sagitta bohemica* were found in a bioclastic dolomite ("capping turbidite") (sample 9a, just below 8a stratigraphically). The first subspecies has a known range of early Wenlockian to possibly earliest Ludlovian, whereas the second subspecies is more restricted to the later Wenlockian through earliest Ludlovian. These interreef strata were deposited later than most of the extant reef, which, therefore, is no younger than earliest Ludlovian.

Middle Pit-Main Level The Middle Pit, largest of the six pits, is the location of the primary crusher. Rock quarried from all pits is brought here in 85-ton haulage trucks. The crusher operates like a giant mortar and pestle, reducing rocks to diameters of nine inches (23 cm) or less, which are then transported via conveyor belt to secondary and tertiary crushers in the South Pit.

Opened in 1924, the Middle Pit (referred to as the North Quarry until the mid-1950s) initially consisted of a shallow, narrow, north-south cut that was eventually extended to about the present position of the interstate (Fig. 10). The opening of this pit verified that the entire rock hill was reef-controlled, as demonstrated by the radially-oriented dip which changes direction from southeast to east and then northeast through the exposure. This cut, in conjunction with the Trolley quarry, allowed Bretz (1939) to produce a block diagram of the entire reef (Fig. 17). By 1950, much of the Middle Pit had been excavated to a depth of about 50 feet (15 m). These new exposures, in conjunction with those in the South Pit, formed the basis for much of Heinz Lowenstam's classic work on the biologic and sedimentologic succession in Silurian reefs, serving as the model for his rough-water stage of reef development (Fig. 18).

One recent controversy centered on the Middle Pit involves the location and volume of the reef core. In his block diagram, Bretz (1939) (Fig. 17) suggested that the reef core may be bisected by the B. & O. railroad tracks, and Willman, *et al.* (1950) believed they saw substantial core rock along the west wall of the Middle Pit in the approximate location predicted earlier by Bretz. By the time Ingels began his study of Thornton in the late 1950s, massive reef core could no longer be seen in this area, but he did report a much smaller patch of reef core (part of his Stromatoporoid Biosome) a short distance to the north (Ingels, 1963) (Fig. 19, 20). There are two possible explanations for this difference between the earlier and later observations: 1) No core rock ever existed in the area of

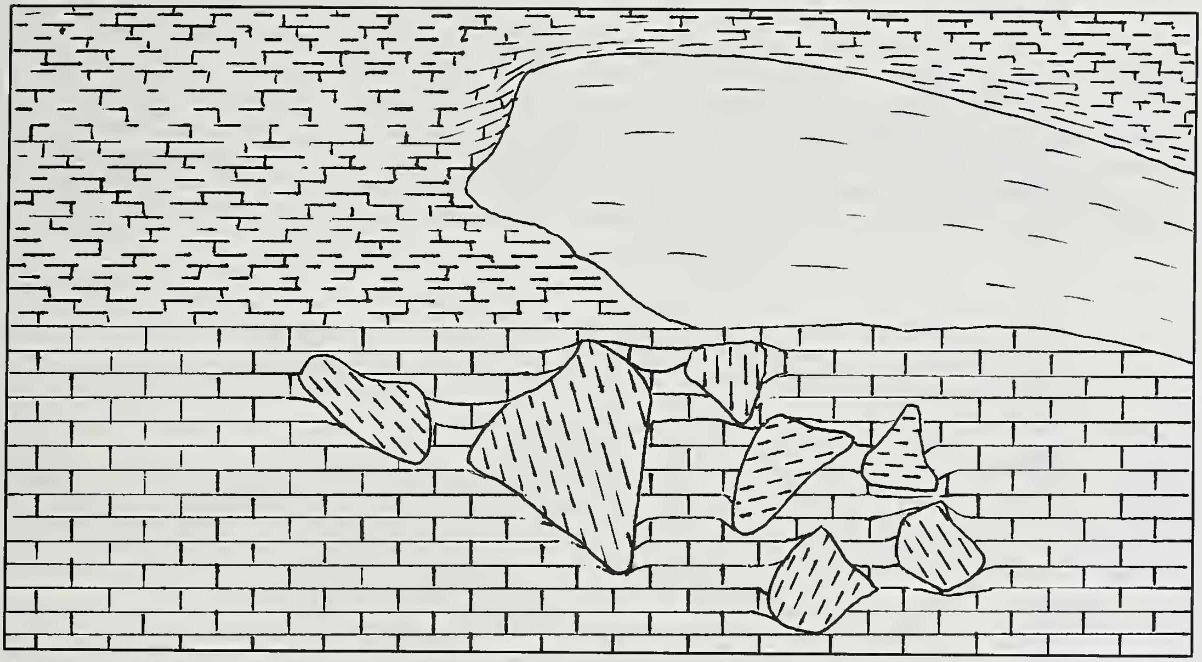


Figure 16 ***Top:*** Bretz's reef 120 feet (36 m) north of megaclast in Figure 15 in the west wall of the South Pit, Thornton quarry. "Capping turbidite" appears as light-colored bed in left center of photo. Wall is 45 feet (14 m) high (Photo taken August, 1976). ***Bottom:*** Bretz's diagram of this reef showing displaced blocks of reef rock within breccia. (After Bretz, 1939).

the Willman, *et al.* (1950) observations. The center of the reef is now known to be located west of the railroad tracks. Furthermore, dipping strata along the west wall of the Middle Pit show a dip reversal centered near the main tunnel that does not seem to reflect any core rock in the vicinity of the 1950 observation. Bedding is very weak in the area of dip reversal near the center of the reef, and what Willman, *et al.* (1950) interpreted as massive core rock may have been related to dip reversal. 2) The Stromatoporoid Biosome described by Ingels (1963) is part of the core observed by Willman, *et al.* (1950), most of which had been quarried away. The Stromatoporoid Biosome exposure mapped by Ingels (1963) (Fig. 19) may actually have extended farther to southeast as indicated on his paleoecologic map (Fig. 20), paralleling the trend of his other core biosomes through the area where Willman, *et al.* (1950) sighted core rock. Their map of the area indicates that the core exposure was located about 300 feet (92 m) east of the railroad tracks, which would place it a significant distance east of the existing quarry wall. Therefore, it is entirely plausible that Ingels' Stromatoporoid Biosome exposure is only the north end of the core observed by Willman, *et al.* (1950) when the quarry wall was located farther to the east. Interestingly, both Lowenstam (personal communication, 1980) and Ingels (1963) observed distinct "growth surfaces" in this massive rock. Unfortunately, Ingels' exposure is now inaccessible, located about 160 feet (49 m) above the present quarry floor just west of the main sump.

Descending the ramp to the main level of the Middle Pit, one can observe the dip of flank strata increasing to about 40°, although bedding becomes obscure in the west wall in the vicinity of the main tunnel. Vuggy, biomoldic and intraparticle porosity in the upper 70 feet (21 m) of reef strata commonly is filled with asphalt, which can be seen oozing from vugs in the upper part of the south wall along the ramp. The reef is a fossil oil reservoir, and the lower boundary of asphalt occurrence may mark the oil-water contact (McGovney, 1978). A large iron-stained clay-filled fissure near the southwest corner of the pit contains silicified corals and stromatoporoids. Devonian shark teeth were found in a fissure located in the northeast corner of the South Pit (Bretz, 1939), which has since been quarried away.

The quarry is 160 feet (49 m) deep at the main tunnel beneath the B. & O. railroad tracks. The center of the reef is located just west of the tunnel, and a reversal in dip of the flank strata from 35° southeast to 40° northeast can be seen here. Flank strata proximal to the upper core area are obscurely bedded, particularly at the point of dip reversal, yielding an almost massive appearance. Generally, reef flanks follow a trend from obscure and irregular near the core to well-defined and thinner-bedded distally. Throughout most of the reef, flank strata radiate out from the central reef core with a fairly uniform dip of 30° to 40° before levelling out into interreef strata. Flank strata on

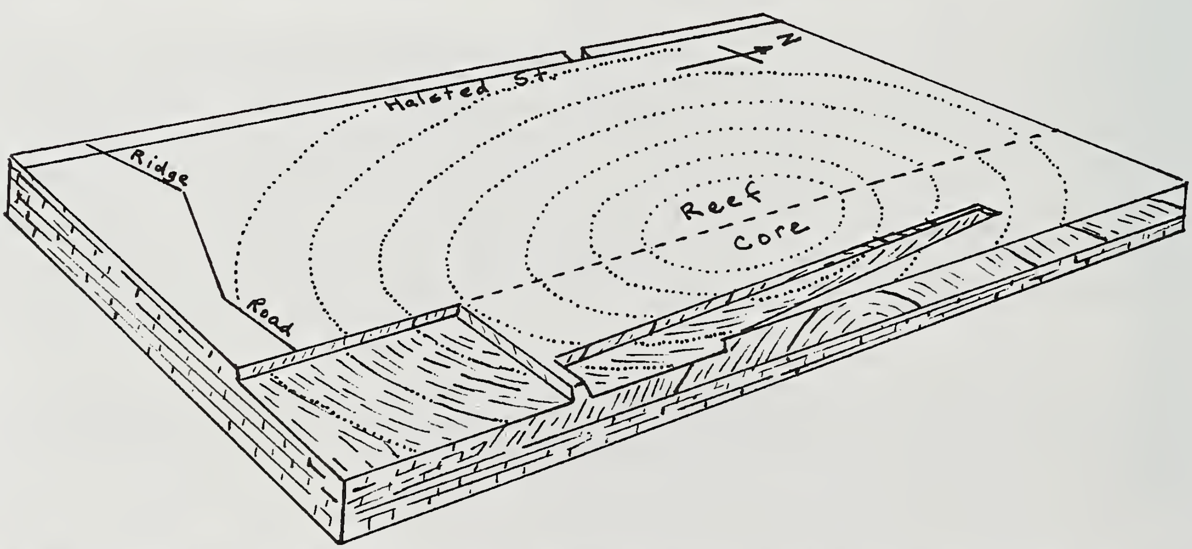


Figure 17 Bretz's block diagram of Thornton Reef showing location of the Trolley (Interurban) quarry and South Pit and the long cut through the Middle (then North) Pit, Thornton quarry. (After Bretz, 1939)

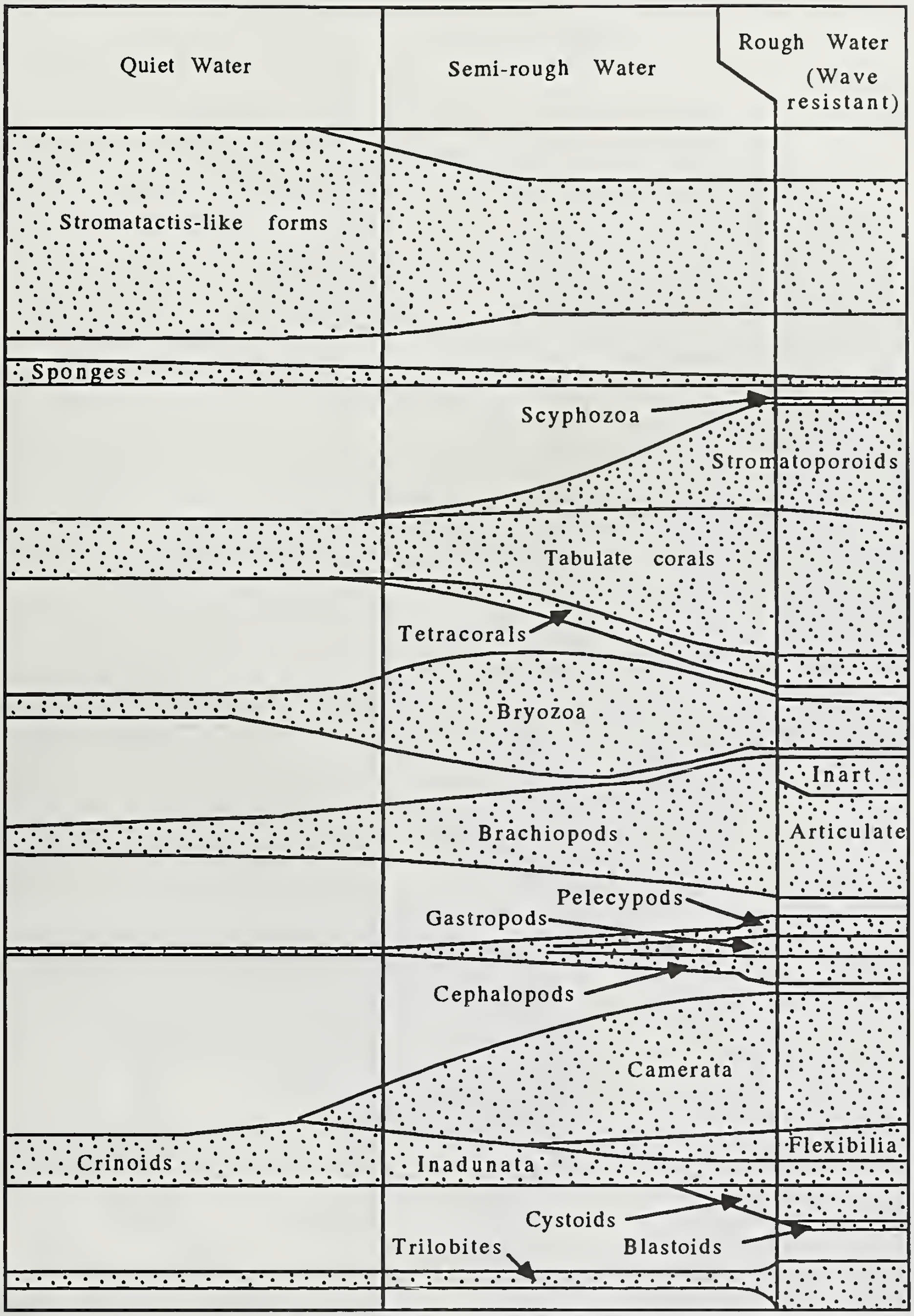


Figure 18 Lowenstam's diagram showing succession of "Niagaran" reef faunas, which was based on the exposures he studied in the South and Middle Pits, Thornton quarry. (After Lowenstam, *et al.*, 1956)

the east and northeast are exceptions to this trend as they exhibit dips of only 10° to 20° (Ingels, 1963) (Fig. 21). This suggests an asymmetry of reef configuration that Ingels interpreted as a leeward buildup of reef-derived debris.

The well-defined flank strata of the Middle Pit are interrupted by a number of large, generally structureless bodies, which are best seen in the east wall. Typically, these consist of vuggy, porous, highly crystalline, medium gray dolomite, and display domed and slightly expanded tops. Surrounding flank strata of a different lithology wedge out against these bodies and change dip relative to

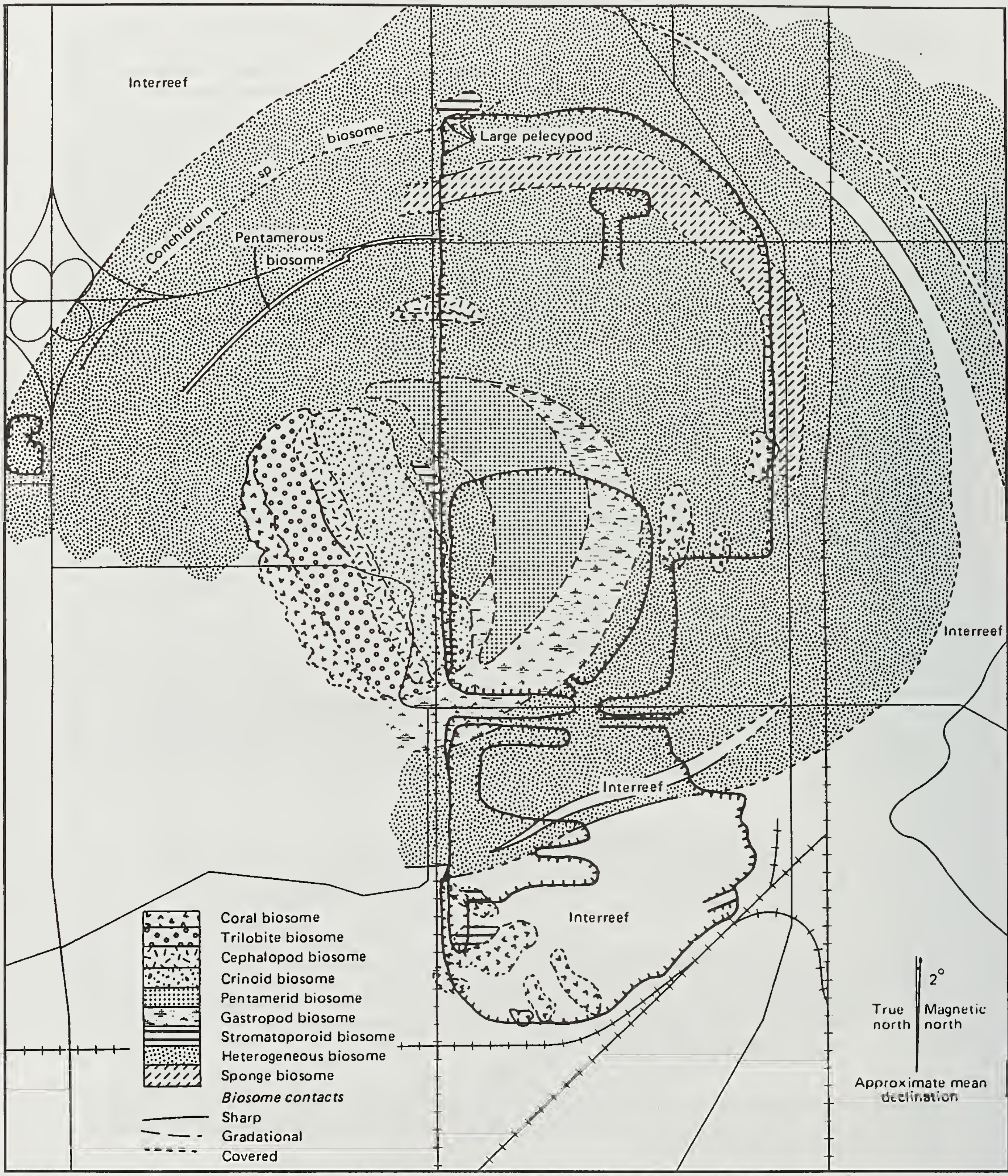


Figure 19 Ingels' biosome distribution map of the Thornton Reef. (Redrawn from Ingels, 1963)

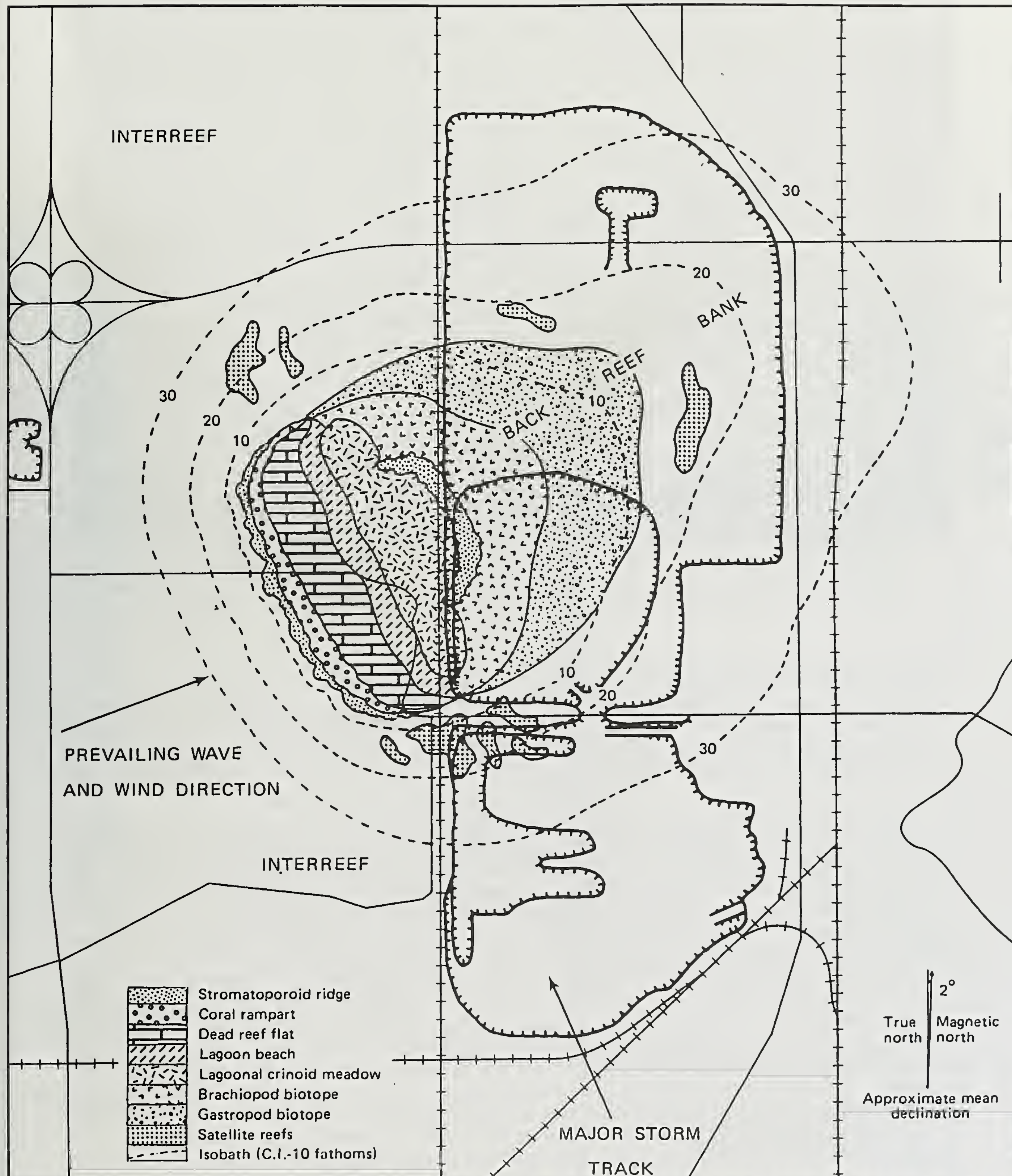


Figure 20 Ingels' paleoecologic map showing a restoration of Thornton Reef 300 feet above its base, with the interpreted distribution of biotopes in relation to prevailing winds, reef morphology and inferred bathymetry. Note that the windward stromatoporoid ridge in entirely hypothetical. (Redrawn from Ingels, 1963)

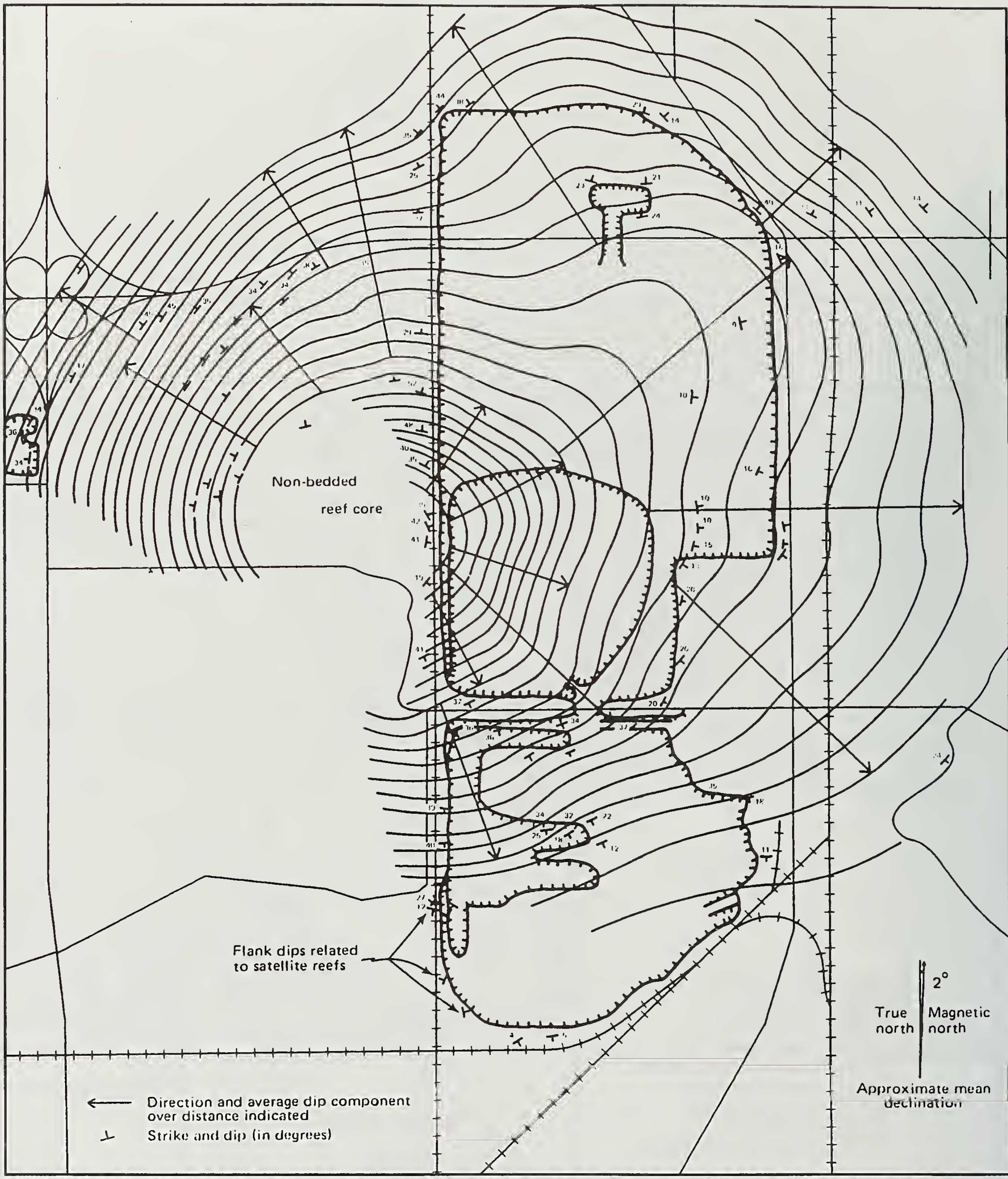


Figure 21 Ingels' form line map showing configuration of Thornton Reef based on strike and dip data. (Redrawn from Ingels, 1963)

Figure 22 Base of slab of a localized accumulation of the trilobite *Bumastus (Cybantyx) insignis*, showing dominant convex-downward orientation of disarticulated cranidia and pygidia (USNM 181894). Specimens collected from sediment trap in now-covered structureless body at south end of the east wall, main level, Middle Pit, Thornton quarry.

them. In some bodies, large colonies of tabulate corals, especially *Halysites,* and stromatoporoids form a framework fabric. Internal sediment of very finely crystalline, dense, nonporous, almost white dolomite fills numerous large interstitial cavities between the colonies. Accumulations of cephalopods and trilobite parts and laminated sediment are characteristic of these fills or sediment traps. Similar sediment is present at the sides of the some bodies, apparently in current shadow zones.

These localized accumulations of cephalopods and disarticulated trilobites are typical of sediment traps formed by cavities and current shadow zones (Mikulic, 1976, 1979; Mikulic, *et al.,* 1983) (Fig. 22). Although size of the accumulation varies with size of the trap, most are only a few inches wide and lenticular in shape. Density of specimen packing also varies and is to some extent independent of the size and shape of the sediment trap. Typically, they contain only a few cephalopods or trilobite parts; however, very large accumulations containing tens of thousands of specimens have been found here. The trilobite cranidia and pygidia are oriented predominantly convex-downward, indicating that they settled out in quiet water (Mikulic, 1979). Orthoconic cephalopods lie horizontal in most cases, but a few inclined specimens occur in traps with diameters smaller than the length of the cephalopods. These accumulations are taphonomic features resulting from current transport of trilobite molts and empty cephalopod shells. Most of the trilobite and cephalopod specimens found at Thornton are from these accumulations. Although the Thornton accumulations are overwhelmingly dominated by the trilobite *Bumastus (Cybantyx) insignis,* fourteen trilobite and at least five cephalopod species have been collected, along with various brachiopods, gastropods and bryozoans. Rare chiton plates also occur (Kluessendorf, 1987). These accumulations are also present in the proximal flank strata of the Coral Biosome, but in the distal flanks, they are confined to the structureless bodies.

Presence of these taphonomic accumulations within the structureless bodies indicates that the bodies had relief above the sea floor and were well lithified because they contained fractures, cavities and depressions that acted as sediment traps. For the most part, the composition of the bodies is lithologically and paleontologically identical to the Coral Biosome and other proximal flank strata, whereas Crinoid Biosome and lower core rock are absent. The bodies are commonly associated with massive, rubbly-textured, brecciated rock. Their tops typically are domed and expand outward asymmetrically, suggesting some current influence possibly on the leeward side. Flank strata wedge out, or abut against, the bodies and underlying or adjacent flank beds may be crumpled. The majority are confined to the distal flank strata and none are found in the Crinoid or Coral Biosomes. Although much is known about these structureless bodies, their origin is somewhat equivocal. Ingels (1963) interpreted some bodies, which can still be seen near the top of the east wall, as satellite reefs. On the other hand, McGovney (1978) identified the structureless bodies as megabreccia containing large megaclasts derived from higher parts of the reef. One of the megaclasts along the east wall was at least 60 feet (19 m) long, almost 100 feet (31 m) wide and characterized by beds dipping 70° south. Geopetal fabric and fossil orientation agree with this dip, indicating that the clast is a displaced block of proximal reef flank facies. Locally, unbedded lithoclasts of various sizes, many of which are neither reef flank nor core lithologies, occur in the surrounding megabreccia. Although origin of some of the bodies may be polygenetic, it is probable that the majority are megaclasts such as those in the South Pit. However, a few satellite reefs may have grown in the flanks and reefal organisms may have colonized the tops of some of the megaclasts after their deposition in the flanks. Megabreccia deposits are most numerous on the leeward side of the reef as exposed in the Middle Pit, and historical descriptions suggest that they were also common along the reef margin in the South Pit. To date, they are noticeably less common and smaller in size in the Northwest and Brown Derby pits, although they may increase as these areas are quarried farther out from the reef center.

Northwest Pit-Upper Reef Core The entire area west of the railroad tracks has been quarried out since the late 1960s. Ingels was the first to study this area when, in the late 1950s, much of the Northwest Pit area was stripped down to bedrock surface. He was able to differentiate a number of parallel-trending bio- and lithosomes, which marked the center and high-energy margin of his main reef body, as depicted on his often-reproduced reef model (Fig. 19, 20). However, most of the area north of the Brown Derby Pit was quarried down to the 160 foot-level (49 m) without study. Based on the exposure at the main tunnel, Pray (1976) suggested that there was no large expanse of massive reef core as predicted by Bretz, Lowenstam, and others in this part of the reef, nor were Ingels' parallel-trending biosomes and lithosomes present. Instead, Pray recognized the remnants of what he thought to be a small, conical core. Pray (1976) and McGovney (1978, 1988) proposed that this small, symmetrical conical core, lacking any significant high-energy features, was probably a deep-water structure. Their interpretation sparked one of the major controversies surrounding Thornton and other Silurian reefs: Are these typical shallow-water, high-energy reefs or deep-water, low-energy structures?

The center of dip reversal for Thornton reef can be seen just west of the main tunnel in the Northwest Pit (Fig. 9, 23). Although most of the area has been quarried down to a depth of 160 feet (49 m) to the main quarry floor, the southern edge of this dip reversal has been preserved beneath an old ramp adjacent to the main tunnel. The lower part of this exposure displays a triangular or conical area of massive-appearing rock—the upper core—which is in part cement-rich. As the core is traced upward, the rock becomes more pelmatozoan-rich and large colonies of the corals *"Amplexus"* and *Syringopora* become conspicuous. Thick, poorly-defined, steeply-dipping strata surround the core.

The top of the core appears to constrict upward, although a poor exposure at the top of the wall suggests some lateral expansion. These upper strata contain common very large diameter (1 inch; 2.54 cm) pelmatozoan stem sections up to 10 inches (25 cm) long. Large pelmatozoan roots with many cirri, which are absent from other areas of the reef, are common here. Scattered *"Amplexus"* are common and *Syringopora* also occur at the top of the extant core. *Sphaerexochus* is the most common trilobite in the area, but rare elsewhere in the reef except the lower core. Other trilobites include rare *Scottoharpes* and *Rhaxeros*, neither of which has been found in other parts of Thornton Reef or in any other Chicago Silurian reef. This pelmatozoan-rich rock constitutes Ingels' (1963) Crinoid Biosome, the most distinct of the biosomes he described.

Figure 23 Dip reversal at south edge of upper reef core located below old ramp just west of the main tunnel, main level, Northwest Pit, Thornton quarry (Photo taken in 1974). Weakly defined strata may be seen dipping in opposite directions on either side of the power-line tower near center of photo.

In the Brown Derby and Northwest pits, Ingels' (1963) Crinoid Biosome is succeeded laterally by his Cephalopod, Trilobite and Coral Biosomes, which we consider to represent only a single biosome (Mikulic, *et al.,* 1983). The latter is characterized by a diverse biota, including stromatoporoids and tabulate corals such as *Favosites,* and by the rarity of large-diameter pelmatozoan debris. Nearest the Crinoid Biosome, Coral Biosome strata are thick-bedded and weakly defined, but away from the reef core these strata thin and become well defined. Farther outward, cyclically-bedded reef flank strata with a lower diverse biota occur. The biota in a few of these strata is virtually monotaxic, as demonstrated by Ingels' (1963) Pentamerid Biosome, which is confined to an arcuate band along the west half of the reef about 2250 feet (692 m) from its center. This biosome is composed of abundant disarticulated valves of the pentameriid brachiopod *Kirkidium,* which form several layers of graded, well-cemented rudstone throughout a six foot (2 m) interval of flank strata (Fig. 24). Matrix is rare and isopachous rim cement coats and lines many of the valves, suggesting that the brachiopods were deposited under well-winnowed, high-energy conditions.

Middle Pit-Lower Level The lower 100 foot-deep (31 m) level of the Middle Pit was opened in 1979. It exposes proximal and distal flank strata and, more importantly, the reef-interreef transition in a position much closer to the reef core than was exposed in the South Pit.

Near the sump south of the tunnel, proximal flank strata, which are an extension of the Crinoid Biosome, contain common pelmatozoan debris. North of the tunnel, flank strata are thick-bedded, porous, nearly white, highly crystalline, very fossiliferous dolomite. The fauna is characterized by the inarticulate brachiopod *Dinobolus* and molluscs, especially gastropods and large articulated bivalves. A variety of articulate brachiopods, orthoconic cephalopods, rugose and tabulate corals, and pelmatozoan debris are present as well. Some of the flank strata here are dominated by extremely abundant, densely packed, grain-supported, disarticulated valves of small (0.5 inch; 1.3 cm) smooth-shelled brachiopods that are coated with isopachous rim cement and may occur in normally-graded beds. Flank strata in the vicinity of the tunnel are generally thin-bedded and dip about 35° north. About two-thirds of the distance down the west wall, however, they begin to gradually level out as

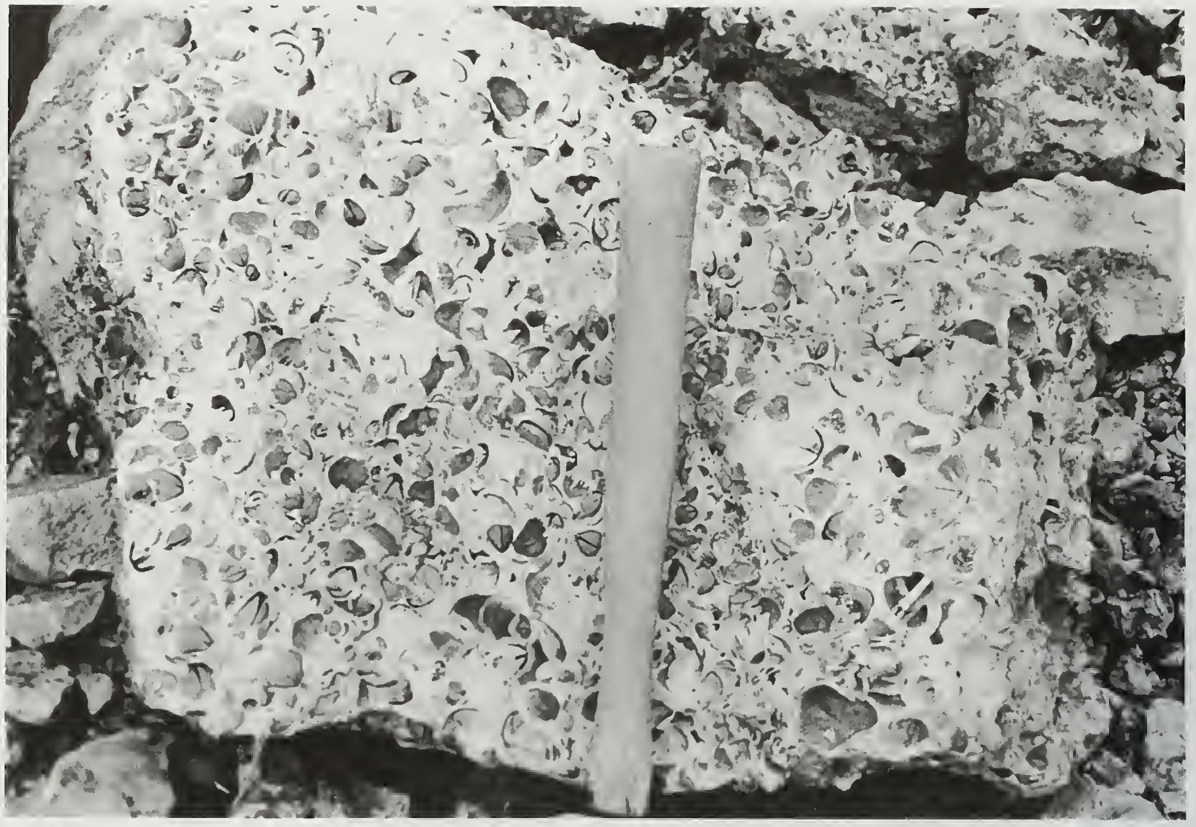


Figure 24 Block containing abundant, densely packed, disarticulated valves of the pentameriid brachiopod *Kirkidium* from near the bedrock surface in the southwest corner of the Northwest Pit, Thornton quarry.

they approach the underlying interreef strata near the quarry floor. Approximately five feet (2 m) of interreef strata, which dip rapidly toward the south, are exposed near the northwest corner. From the middle of the west wall northward, a number of thick massive beds or lenses of megabreccia, consisting of medium gray, vuggy dolomite with corals and stromatoporoids, interbed with or interrupt normal flank strata near the reef-interreef transition. A large volume of reef-derived debris, including corals and stromatoporoids, can be seen piled up at the toe of the flanks along this transition in both the Middle and Northwest pits. Near the northeast corner, reef detritus overlying interreef strata appears to contain clasts of interreef lithology, and beneath it the uppermost interreef is marked by vertical burrows or borings. These features imply that the interreef surface here was probably consolidated, or lithified, to some extent prior to deposition of the reef-derived material. Normal steeply-dipping flank strata in the south wall level out abruptly and wedge out against three feet (1 m) of interreef strata. Elsewhere in this pit, interreef strata both interfinger with, and grade into, flank strata. Groundwater commonly seeps out through these strata giving them an iron-stained appearance. This is one of the few places in the quarry where water can be seen regularly flowing out of the rock walls. Most of the reef proper, including joints near the surface, does not appear to be a significant conduit for water flow.

The interreef strata at this level of the Middle Pit differ from those in the South Pit. Here, they are dense, only slightly argillaceous, and well-bedded, occurring as medium beds of gray dolomite with bright green argillaceous partings. Nodular bedding is absent. These appear to be true interreef strata, but they were greatly influenced by influx of reef-derived sediments as reflected by their higher carbonate content. Rare shaley interreef strata, containing dendroid graptolites and other fossils atypical of the reef, extend into the reef from the north. The rise in the reef-interreef contact to the north and east demonstrates the convex-downward bowl shape of the base of the reef as described by McGovney (1978) from subsurface data. As the reef grew outward, it prograded over increasingly thicker and younger interreef sediments so that, through time, the bottom of the reef margin occurred at ever-higher levels. This also indicates that reef sediments were being deposited more quickly than surrounding interreef sediments. As this lower level is expanded eastward, the reef-interreef contact should rise higher still.

Northwest Pit-Lower Reef Core The lower level of the Northwest Pit, which was opened in 1983, is presently 100 feet (31 m) deep. As quarrying progressed westward from the tunnel, an elongate (1400 feet, 430 m) core ridge was quarried through (Fig. 25). Presence of core rock at this location contrasts with the steeply-dipping proximal flank beds that are predicted in this portion of the reef by the conical core model of Pray (1976) and McGovney (1978, 1988). Rather, the northwest-southeast trend of this lower core ridge follows precisely the trend of the inner core biosomes that Ingels (1963) observed on the stripped bedrock surface 260 feet above the quarry floor here. Throughout most of the lower level, this core ridge has since been quarried away, but a cross-section through it is preserved in the eastern portion of the south wall (Fig. 26). From 1985 until 1989, this wall was not quarried, which allowed significant weathering to take place, enhancing the exposure and permitting detailed study of this critical feature. This cross-section revealed that the core ridge, which is delineated by a conspicuous dip reversal from northeast to southwest, is about 180 feet (55 m) wide at the present quarry floor, and narrows upward to a peak near the top of the wall. Near the center of the lower core was an inner "mound" marked by a broad dip reversal from east to west, as defined by orientation of corals and cement patches. In general, the fauna of the lower core is of low diversity. The inner mound was composed predominantly of the fasciculate colonial rugose coral *"Pycnostylus,"* characterized by abundant thin, tubular corallites, and the tabulate *Halysites,* here occurring as ribbon-like colonies. Abundant isopachous and botryoidal cement coats corallites, fills void space within and between them, and lines cavities such as shelter porosity beneath platy corals. Much of the rest of the lower core displayed well-cemented, steep, westward-dipping beds composed of huge masses of *"Pycnostylus,"* long, cylindrical solitary rugose corals and ribbon-like *Halysites* colonies, apparently interbedded and in growth position. The corals grew preferentially toward the southwest as evidenced by successive layers of *in situ* colonies, giving the core a prominent asymmetry (Mikulic and Kluessendorf, 1992). [Coincidentally, Ingels' (1963) postulated paleowind direction was also from the southwest.] The corals within the inner mound and in these dipping beds impart a conspicuous bindstone-framestone framework to the core, one of the most pronounced of any reef in the area. A drill-core revealed that *"Pycnostylus"* extends at least 40 feet (12 m) below the quarry floor. The eastern portion of the lower core comprises beds of bioclastic debris, including *"Pycnostylus"* and *Halysites* fragments, that dip less steeply than the coral beds on the west.

Features within the lower core changed in prominence and position as the wall was subsequently quarried farther south. The inner mound shifted to the west, and now is situated nearly at the western edge of the lower core. Abundant, heavily cemented, bands of platy corals, such as *Heliolites* and sheet-like *Favosites,* dominated the inner mound in later exposures. The *in situ "Pycnostylus"* masses continue to characterize the western edge of the core. It appears that the core ridge is reaching its southern edge in the present exposure as the predominance and location of the coral framework have shifted toward its western edge and the bioclastic beds to the east have increased in volume dramatically.

The outer boundary of the lower core is a mineralized, corroded, irregular, scalloped surface. The fauna changes abruptly across this boundary from the coral-dominated fauna within the core to the pelmatozoan-dominated flank strata that bury it but do not interbed with core rock (Figs. 26 to 28). Pelmatozoan debris in these proximal grainstone and packstone flank beds consists mostly of large diameter (0.5 inch; 1.25 cm), short stem sections, generally lying parallel to bedding. These flank strata occur in two sets: the lower set, which dips more steeply than the upper, wedges out against the core and is truncated by the upper set, but the dip of both sets reflects the configuration of the lower core ridge.

These pelmatozoan-rich flanks extend about 400 feet (123 m) to the west along the south wall. Their dip decreases from about 37° to 24° near a massive light-colored flank bed (Fig. 27C). A dramatic faunal change takes place to the west. Here the pelmatozoan flanks and *"Pycnostylus"* dominated

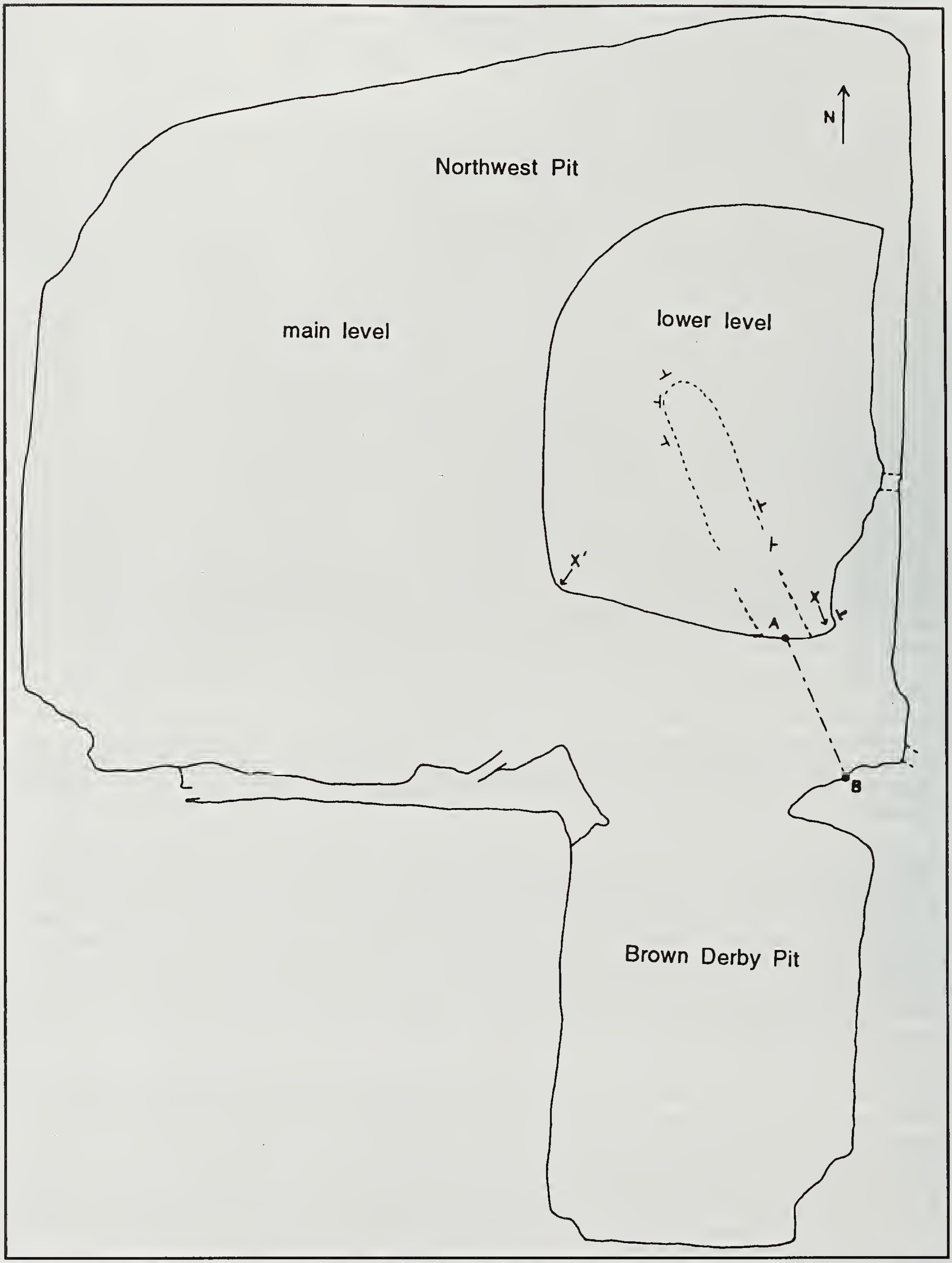


Figure 25 Map showing position of core ridge in the lower level of the Northwest Pit, Thornton quarry. Outline of Northwest Pit is as it appeared in 1987. Dashed line indicates portion of core ridge removed by quarrying during the early 1980s. Line A-B connects peaks of upper and lower core ridges. See Fig. 27 for cross-section along line X-X′.

Figure 26 Photo showing cross-section through the lower core ridge in the south wall, lower level, Northwest Pit, Thornton quarry, as it appeared in 1987. Note asymmetry of core ridge with growth surfaces to the southwest (right). Wall is approximately 100 feet (31 m) high.

coral framework are succeeded by flank beds that contain a high diversity fauna, which is characterized by the coral-stromatoporoid-pentameriid brachiopod biota (Ingels' Coral, Cephalopod and Trilobite biosomes) that composes most of the extant reef volume (Fig. 27D). In these flanks, the halysitid corals occur as fan-shaped colonies and favositid corals and stromatoporoids display robust, domal morphologies; these taxa are associated with *"Amplexus"* and a wide variety of other tabulate and rugose corals (Mikulic and Kluessendorf, 1992). The colonies commonly are scattered, appear to have been transported and may have been overturned. Coinciding with this faunal change is a dramatic change in the angle of flank dip to 43°. The first appearance of megabreccia deposits correlates with these more steeply dipping flanks. These flank strata have a pronounced cyclically-banded appearance (Lowenstam, 1952) where the lighter-colored bands of bioclastic debris grading up into darker micrite bands (Fig. 27E). In general, the individual bands are not continuous but may pinch out both up- and down-dip. The west and north walls and the north half of the east wall expose similar flank strata. The reef-interreef contact occurs near the quarry floor in the north wall, and displays features similar to the contact in the lower level of the Middle Pit.

Depositional Model Based on present observations and exposures, a revised depositional model for Thornton Reef can be proposed. As the quarry expands and new levels are excavated, it is expected that some of these interpretations will be modified, as have all previous models of the reef.

1. The *"Pycnostylus"*-dominated lower reef core forms a 1400 foot-long (430 m) elongate ridge, not a much smaller cone-like reef core as proposed by Pray (1976) and McGovney (1978). It is unknown exactly how the lower core exposures were reflected in the upper 160 feet (53 m) of the quarry as this entire area was removed without study. It is apparent, however, that the trend of the core ridge parallels the trend of Ingels' (1963) elongate core biosomes and underlies much of his non-bedded reef core or Crinoid Biosome.

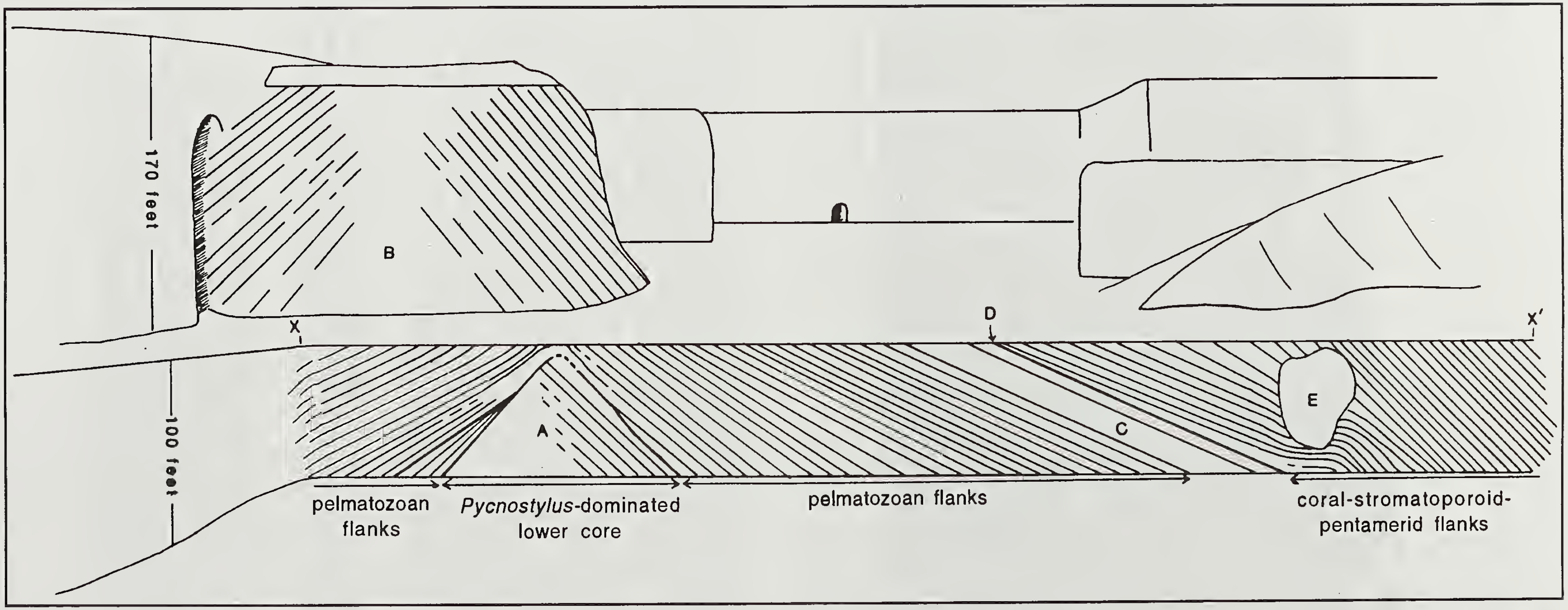


Figure 27 Diagram of the south wall, lower level, Northwest Pit looking south toward Brown Derby Pit, Thornton quarry, showing relationship of lower core ridge (A) to upper core (B) near main tunnel. The diagram also shows the lateral succession from the "*Pycnostylus*"-dominated lower core ridge to pelmatozoan-rich flank strata to deeply dipping flank strata characterized by stromatoporoids and corals and the appearance of megabreccia. C=massive, light-colored flank bed; D=prominent bedding plane; E=megabreccia. X-X′ corresponds to line on Fig 24.

Figure 28 Photo (1988) of the south wall, lower level, Northwest Pit, Thornton quarry, showing features diagrammed in Figure 27. Note that photo is taken from northwest, whereas Figure 27 is drawn from a due north perspective.

2. The lower core exposure is asymmetrical in cross-section. An inner zone having a framework of platy corals is succeeded by a framework of massive fasciculate and platy coral colonies that displays a shift in growth towards the southwest, which is also the paleowind direction interpreted by Ingels (1963) on the basis of independent evidence. McGovney (1978) reported a similar asymmetry in the upper core exposure (Fig. 27B).

3. Pelmatozoan-rich flank strata wedge out against the sides of the core and may possibly bury it completely at a higher level. Dip and strike of these flanks reflect the configuration of the core ridge and not the general north to northwest dips characteristic of more distal portions of the northwest quadrant of the reef. The dip of the pelmatozoan flanks is steepest (38°) near the core and decreases gradually outward to 24°. These flanks form a second generation core area.

4. The pelmatozoan-rich strata show vertical zonation along dip. Robust roots, apparently in growth position, and long stem sections are common near the bedrock surface above the upper core exposure. Roots are very rare down-dip in the lower flank strata. Stem sections in these lower beds form a grainstone, whereas stems at the top of the core are less densely packed. This suggests that the pelmatozoans were living at the top of the core and that the flanks consist of debris transported downslope. This volumetrically significant amount of downslope transport indicates a certain level of current or wave activity, and receptaculitids associated with the pelmatozoans suggest that this part of the reef was situated within the photic zone.

5. An abrupt change in the angle of dip accompanied by a change in lithology and biota occurs in the cyclically-banded flank strata that succeed the pelmatozoan-rich flanks distally. This change is marked by an increase in dip to 43° and the appearance of a coral-stromatoporoid-pentameriid brachiopod biota. A similar change in dip was reported by McGovney (1978; his Fig. 27) along the west wall of the Middle Pit, north of the main tunnel. Megabreccia deposits first appear in these distal flank strata, corresponding to this change in dip, lithology and biota; they become more numerous farther from the core. In the Middle Pit, to the east, distal flanks dip at much lower angles and are composed of finer-grained material, which Ingels (1963) interpreted as indicating deposits leeward of the reef crest.

6. This shift in the type of flank strata marks a different stage of reef development, probably into a higher energy environment, which was inhabited by a different biota. Intensified energy related to storms and waves may have increased sedimentation rate, generating lateral growth of the reef and producing steeper flank strata which inundated the underlying, more gently-dipping, pelmatozoan-rich proximal flanks. The appearance of megabreccia deposits, possibly resulting from intense storms, supports the higher energy interpretation.

7. The surrounding interreef, or open platform, strata are typically argillaceous and contain a low-diversity biota unlike that found within the reef. Reef-derived debris interfingers with, and may influence, characteristics of proximal interreef strata in places.

8. The exposures at Thornton reveal a three-part succession of reef development:

a. The earliest stage comprises an elongate core ridge characterized by a coral framework dominated by massive fasciculate colonies of *"Pycnostylus"* in association with platy corals. Many of the organisms in this part of the reef appear to be *in situ*. This stage may have developed below normal wave base, but pronounced lateral zonation and preferential growth of the corals indicates some directional influence of waves or currents. This *"Pycnostylus-"* dominated framework has been found in the earliest developmental stage of some other Silurian reefs regardless of their size (Mikulic and Kluessendorf, 1992).

b. The pelmatozoan-rich grainstone proximal flanks compose the second stage. These appear to be dominantly downslope gravity deposits of pelmatozoan debris, some of which was generated at or near the top of the extant upper core. The pelmatozoan flanks sharply overlie the truncated surface of the core ridge. This abrupt change in biota and depositional style suggests an increase in energy, likely coinciding with growth of the reef into storm wave base.

c. The coral-stromatoproid-pentameriid brachiopod flank strata represent the third stage. The site of reef growth during this stage is not preserved in the truncated extant reef; only the materials derived from it are represented. A change in coral morphology from fasciculate masses or platy colonies in the earliest stage to robust and domal in this stage suggests an increase in wave energy, as does the frequency of colony overturn. The increased angle of flank dip suggests that the reef was prograding outward over underlying flanks, and the abundance of these reef-derived bioclastic flanks implies that erosion was vigorous. The appearance of megabreccia deposits at this level further indicates that available energy was capable of dislodging large amounts and huge chucks of lithified material and transporting it downslope and even leeward of the reef. This stage probably indicates that the reef had reached sea level and higher wave energy, including intense storms, capable of producing increased sediment, bioclastic debris, and even megaclasts.

This model depicts a generally shallowing-upward sequence that reflects changes in sea level, wave energy, reef growth, nutrient flux or a combination thereof. These stages are also found in other Silurian reefs to varying extent. The coral colonies show a bathymetric morphological zonation (platy to fasciculate to domal) related to decreasing water depth and increasing energy. This zonation is similar to the coral zonation displayed by modern reefs located entirely within the photic zone (see Hallock and Schlager, 1986). Although absolute depths are unknown, even the lower core ridge exhibits some directional influence as indicated by the asymmetric growth of the coral framework. Also, receptaculitids in the pelmatozoan flanks imply that some of these were located within the photic zone. The abundance and fabric (dominantly isopachous and botryoidal) of cement through all of the developmental stages are indicative of fairly shallow, well-circulating water like that found in modern reef margins (Harris, *et al.*, 1985). Progradation of the final stage of reef development represented suggests that by then sea level had become static, that sea level fluctuations were small, and/or that reef growth had outpaced changes in water depth.

ACKNOWLEDGMENTS

We would like to thank the City of Chicago Department of Streets and Sanitation for permission to visit the Bridgeport Quarry site and for assistance in our research. We would also like to thank the Crown family for allowing research and field trips in the Thornton quarry over the last fifty years. In addition, we appreciate the assistance provided by the following past and present Material Service employees: Don Stewart, Arnold Sobel, Lyndon Dean, John Halloran, Peter Gaich, Don Wilson, Phil Peters, Brian Rice, Nancy Doyle, Ron Hartman, Morris Lawereins, Brenda Garcia, Gus Nare, John Gulich, Leslie Sonnabend, and John Peltz. Elwood Atherton, Francis Pettijohn, George Otto, Mildred Fenton, and Ruth Doggett Terzaghi provided information about the University of Chicago field trips to Stony Island and the early research there.

REFERENCES

Alden, W. C. 1902. Description of the Chicago district: Chicago Folio, No. 81, Geologic Atlas of the United States. U. S. Geological Survey, 14 p.

Andreas, A. T. 1884. History of Cook County, Illinois. A. T. Andreas, Publisher, Chicago, 888 pp.

Andreas, A. T. 1886. History of Chicago, Illinois. A. T. Andreas, Publisher, Chicago, 876 pp.

Baber, Zonia. 1917. Stony Island: A plea for its conservation. The Geographical Society of Chicago, Excursion Guide No. 3, 16 pp.

Ball, J. R., and K. F. Greacen. 1946. Catalog of the Egan collection of Silurian invertebrate fossils at the Chicago Academy of Science. Chicago Academy of Science Special Publication 7, 55 pp.

Bannister, H. M. 1868. Geology of Cook County. *In* A. H. Worthen, Geological Survey of Illinois, v. III. Geological Survey of Illinois, p. 239-256.

Berry, W. B. N., and A. J. Boucot. 1970. Correlation of the North American Silurian rocks. Geological Society of America Special Paper 102, 289 p.

Bretz, J Harlan. 1939. Geology of the Chicago region—general. Illinois State Geological Survey Bulletin 65, pt. I, 118 pp.

Bretz, J Harlan. 1943. Chicago area geological maps. Illinois State Geological Survey; reissued as Illinois State Geological Survey Bulletin 65, pt II (supplement).

Cumings, E. R., and R. R. Shrock. 1928. Niagaran coral reefs of Indiana and adjacent states and their stratigraphic relations. Geological Society of America Bulletin 39: 579-619.

Doggett, R. A. 1925. Origin of the abnormally steep dips in the Niagaran reefs of the Chicago region. M. S. thesis, University of Chicago, 27 pp.

Fenton, C. L. 1931. Niagaran stromatoporoid reefs of the Chicago region. American Midland Naturalist 12 (7): 203-212.

Gorby, S. S. 1886. The Wabash Arch. Indiana Department of Geology and Natural History 15th Annual Report: 228-241.

Gutschick, R. C. 1987. The Kentland Dome, Indiana: A structural anomaly. *In* D. L. Biggs (ed.), North-Central Section of the Geological Society of America Centennial Field Guide Volume 3: 337-342.

Hall, James. 1862. Physical geography and general geology. *In* James Hall and J. D. Whitney, Report of the Geological Survey of the State of Wisconsin, Madison, 1: 1-72.

Hall, James. 1865. Account of some new or little known species of fossils from rocks the age of the Niagara group. 18th Report of the New York State Cabinet of Natural History, 1-48.

Hallock, P., and W. Schlager. 1986. Nutrient excess and the demise of coral reefs and carbonate platforms. Palaios 1: 389-398.

Harris, P. M., C.G. St. C. Kendall, and I. Lerche. 1985. Carbonate cementation—a brief review. *In* N. Schneidermann and P. M. Harris (eds), Carbonate Cements. Society of Economic Paleontologists and Mineralogists Special Publication No. 36: 79-95.

Hewitt, R., J. Kluessendorf, and D.G. Mikulic. 1987. Taphonomic control of Silurian nautiloid cephalopods in reef and nonreef environments. Geological Society of America Abstracts with Programs 19(7).

Holt, G. E., and D. A. Pacyga. 1979. Chicago: a historical guide to the neighborhoods: The Loop and South Side. Chicago Historical Society, 174 pp.

Ingels, J. J. C. 1963. Geometry, paleontology, and petrography of Thornton reef complex, Silurian of northeastern Illinois. American Association of Petroleum Geologists Bulletin 47: 405-440.

Keifer and Associates, Inc. 1976. Geotechnical design report for the Calumet system of the tunnel and reservoir plan. Metropolitan Sanitary District of Greater Chicago, 78 pp.

Kluessendorf, J. 1987. First report of Polyplacophora (Mollusca) from the Silurian of North America. Canadian Journal of Earth Science 24 (3): 435-441.

Kluessendorf, J., and Mikulic, D. G. 1992. A Silurian (late Llandovery) sequence boundary in Illinois and Wisconsin: Geological Society of America Abstracts with Programs, v. 24.

Kluessendorf, J., and Mikulic, D. G. An early Silurian sequence boundary in Illinois and Wisconsin. *In* B.J. Witzke, G.A. Ludvigsen and J. Day (eds), Paleozoic Sequence Stratigraphy: Views from the North American Craton. Geological Society of America Paper 306: 177-186.

Kluessendorf, J., D. G. Mikulic, and M. R. Carman. 1988. Distribution and depositional environments of the westernmost Devonian rocks in the Michigan Basin. *In* H. J. McMillan, A. F. Embry, and D. J. Glass (eds.), Devonian of the world, Canadian Society of Petroleum Geologists Memoir 13, 1: 251-263.

Leverett, Frank. 1897. The Pleistocene features and deposits of the Chicago area. Chicago Academy of Science Bulletin 2, 87 pp.

Lowenstam, H. A. 1942. A Niagaran fauna from the Chicago area with Brownsport and Bainbridge affinities. Buffalo Society of Natural Sciences Bulletin 17(3): 36-39.

Lowenstam, H. A. 1948. Biostratigraphic studies of the Niagaran interreef formations in northeastern Illinois. Illinois State Museum Scientific Papers 4, 146 pp.

Lowenstam, H. A. 1949. Niagaran reefs in Illinois and their relation to oil accumulation. Illinois State Geological Survey Report of Investigations 145, 36 pp.

Lowenstam, H. A. 1950. Niagaran reefs of the Great Lakes area. Journal of Geology 58: 430-487.

Lowenstam, H. A. 1952. Some new observations on Niagaran reefs in Illinois. Illinois Academy of Science Transactions 45: 100-107.

Lowenstam, H. A. 1957. Niagaran reefs of the Great Lakes area. Geological Society of America Memoir 67 (2): 215-248.

Lowenstam, H. A., H. B. Willman, and D. H. Swann. 1956. The Niagaran reef at Thornton, Illinois. Illinois State Geological Survey Guidebook No. 4, 19 pp.

McGovney, J. E. E. 1978. Deposition, porosity evolution, and diagenesis of the Thornton reef (Silurian), northeastern Illinois. Ph. D. dissertation, University of Wisconsin-Madison, 447 pp.

McGovney, J. E. E. 1988. Thornton Reef, Silurian, northeastern Illinois. *In* H. H. J. Geldsetzer, N. P. James and G. E. Tebbutt (eds), Reefs, Canada and adjacent area. Canadian Society of Petroleum Geologists Memoir 13: 330-338.

Mikulic, D. G. 1976. Distribution and community succession of trilobites (Thornton reef, Illinois) *In* L. C. Pray, The Thornton reef (Silurian), northeastern Illinois, 1976 revisitation. *In* Silurian reefs, interreef facies and faunal zones of northern Indiana and northeastern Illinois. North Central Section of Geological Society of America Guidebook, Western Michigan State University, Kalamazoo, 70 pp.

Mikulic, D. G. 1979. The paleoecology of Silurian trilobites, with a section on the Silurian stratigraphy of southeastern Wisconsin. Ph. D. dissertation, Oregon State University, Corvallis, 867 pp.

Mikulic, D. G. 1983. Milwaukee's gentlemen paleontologists. Transaction of the Wisconsin Academy of Sciences, Arts & Letters 71(1): 5-20.

Mikulic, D. G. 1987. The Silurian reef at Thornton, Illinois. *In* D. L. Biggs (ed.), North-Central Section of the Geological Society of America Centennial Field Guide Volume 3: 209-212.

Mikulic, D. G. 1989. The Chicago stone industry: A historical perspective. *In* R. E. Hughes and J. C. Bradbury (eds.), Proceedings of the 23rd Forum on the Geology of Industrial Minerals, Illinois State Geological Survey Industrial Mineral Note 102: 83-88.

Mikulic, D. G. 1990. Cross section of the Paleozoic rocks of northeastern Illinois: Implications for subsurface aggregate mining. Illinois State Geological Survey Illinois Minerals 106, 14 pp.

Mikulic, D. G., and J. Goodwin. 1986. Urban encroachment on dolomite resources of the Chicago, Illinois, area. *In* J. D. Glaser and J. Edwards (eds.), Proceedings of the 20th Forum on the Geology of Industrial Minerals: 125-131.

Mikulic, D. G., and J. Kluessendorf. 1985. Classic Silurian reefs of the Chicago area. 49th Annual Tri-State Geological Field Conference guidebook, University of Illinois-Chicago, 45 pp. (reprinted with revisions for Michigan Basin Geological Society Field Excursion, 1988; Field Trip #5, 34th Annual Meeting of the Association of Engineering Geologists, 1991; and Field Trip, Part 1, 1992 American Association of Petroleum Geologists Eastern Section Meeting).

Mikulic, D. G., and J. Kluessendorf. 1992. *"Pycnostylus"*-dominated coral framework in Silurian reefs of the central U. S. Geological Society of America Abstracts with Programs 24.

Mikulic, D. G., and J. Kluessendorf, J. E. E. McGovney, and L. C. Pray. 1983. The classic reef at Thornton, Illinois. *In* R. H. Shaver and J. A. Sunderman (eds.), Field trips in midwestern geology, vol. 1, Indiana Geological Survey and Geological Society of America: 180-190.

Mikulic, D. G., M. L. Sargent, R. D. Norby, and D. R. Kolata. 1985. Silurian geology of the Des Plaines River Valley, northeastern Illinois. Illinois State Geological Survey Guidebook 17, 56 pp.

Pettijohn, F. J. 1984. Memoirs of an unrepentant field geologist: A candid profile of some geologists and their science 1921-1981. University of Chicago Press, 260 pp.

Pray, L. C. 1976. The Thornton reef (Silurian), northeastern Illinois, 1976 revisitation. *In* Silurian reefs, interreef facies and faunal zones of northern Indiana and northeastern Illinois. North Central Section of Geological Society of America Guidebook, Western Michigan State University, Kalamazoo, 70 pp.

Salisbury, R. D., and W. C. Alden. 1899. The geography of Chicago and its environs. The Geographical Society of Chicago Bulletin 1, 64 pp.

Savage, T. E. 1926. Silurian rocks in Illinois. Geological Society of America Bulletin 37(4): 513-533.

Weiner, W. F., and A. F. Koster van Groos. 1976. Petrographic and geochemical study of the formation of chert around the Thornton reef complex, Illinois. Geological Society of America Bulletin 87: 310-318.

Willman, H. B. 1943. High-purity dolomite in Illinois. Illinois State Geological Survey Report of Investigations 90, 87 pp.

Willman, H. B. 1973. Rock stratigraphy of the Silurian System in northeastern and northwestern Illinois. Illinois State Geological Survey Circular 479, 55 pp.

Willman, H. B., H. A. Lowenstam, and L. E. Workman. 1950. Field conference on Niagaran reefs in the Chicago region. Illinois State Geological Survey Guidebook 1, 23 pp.

Winchell, A. N., and O. Marcy. 1865. Enumeration of fossils collected in the Niagara limestone at Chicago, Illinois, with descriptions of several new species. Boston Society of Natural History Memoir 1: 81-113.

Worthen, A. H. 1862. Remarks on the age of the so-called “Leclare Limestone” and “Onondaga Salt-Group” of the Iowa report. American Journal of Science, series 2, no. 97, article VI: 46-48.


STOP 1
Bridgeport quarry
STOP 2
Stony Island
quarries
STOP 3
Thornton quarry
CHICAGO
Winnetka
Kenilworth
Wilmette
Evanston
Skokie
Lincolnwood
Glenview
Northfield
Morton Grove
Niles
Park Ridge
Des Plaines
Mount Prospect
Arlington Heights
Prospect Heights
Rolling Meadows
Schaumburg
Roselle
Elk Grove Village
Wood Dale
Itasca
Bensenville
Rosemont
Schiller Park
Norridge
Harwood Hts.
Franklin Park
Bloomingdale
Addison
Glendale Heights
Northlake
Melrose Park
River Grove
Elmwood Park
Stone Park
Berkeley
Elmhurst
Villa Park
Lombard
Glen Ellyn
Wheaton
River Forest
Oak Park
Bellwood
Maywood
Hillside
Broadview
Forest Park
Oakbrook Terrace
Oak Brook
Westchester
La Grange Park
Brookfield
North Riverside
Riverside
Cicero
Berwyn
Stickney
Lyons
La Grange
Western Springs
Hinsdale
Clarendon Hills
Westmont
Downers Grove
Lisle
Willowbrook
Indian Head Park
McCook
Hodgkins
Countryside
Summit
Justice
Bridgeview
Burr Ridge
Darien
Woodridge
Bolingbrook
Willow Springs
Hickory Hills
Palos Hills
Burbank
Oak Lawn
Chicago Ridge
Evergreen Park
Worth
Alsip
Lemont
Palos Park
Palos Heights
Crestwood
Blue Island
Robbins
Riverdale
Calumet Park
Dolton
Midlothian
Posen
Dixmoor
Harvey
Phoenix
Orland Park
Oak Forest
Markham
Hazel Crest
East Hazel Crest
South Holland
Thornton
Glenwood
Orland Hills
Tinley Park
Country Club Hills
Flossmoor
New Lenox
Mokena
CHICAGO O'HARE INTERNATIONAL AIRPORT
CHICAGO MIDWAY AIRPORT
CHICAGO MEIGS FIELD
ARGONNE NATIONAL LABORATORY
0 1 2 3 4 5 mi
0 1 2 3 4 5 6 7 km